SMITH

Tests of Bond Between

Concrete and Steel

Civil Engineering

B. S.

1908

# TESTS OF BOND BETWEEN CONCRETE AND STEEL

BY

CLAIRE HOWLAND WALLACE SMITH

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## THESIS

FOR THE

## DEGREE OF BACHELOR OF SCIENCE

IN

## CIVIL ENGINEERING

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COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

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PRESENTED, JUNE, 1908

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UNIVERSITY OF ILLINOIS

June 1, 1908

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CLAIRE HOWLAND WALLACE SMITH

ENTITLED TESTS OF BOND BETWEEN CONCRETE AND STEEL

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

A. N. Talbot

D. A. Abrams

Instructor in Charge

APPROVED: Ira O. Baker.

HEAD OF DEPARTMENT OF Civil Engineering

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# I. INTRODUCTION.

## 1. Purpose of Tests.

In reinforced columns and beams for construction purposes, the bond between the concrete and the steel reinforcement is a very important factor. It is the purpose of these tests to investigate the strength of this bond under the different conditions under which reinforced concrete may be used in practice.

## 2. Scope of Tests.

These tests are not representative of practice, but comparative; that is, they do not give the actual bond stress which would be developed in practice, but they give the comparative strength under different conditions. They show how the bond is affected by the size of the reinforcing bar, the shape or form of this bar, the proportions in which the concrete is mixed, the age of the concrete, and the conditions of storage. Investigations of the effect of the size of the reinforcing bar were made by testing pieces containing respectively, 1/2-in., 5/8-in., 3/4-in., 1-in., and 1 1/4-in bars. Those for form of bar were made upon specimens containing the square corrugated bars known as the Johnson bars, and upon others containing the plain round bars. Tests showing the mixture of the concrete were made upon specimens containing the plain round bars, the concrete being mixed in the different proportions, 1-4-8, 1-3-6, 1-2-4, 1-1 1/2-3, and 1-1-2. Tests to show the effect of age of the

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concrete were made upon specimens of 1-2-4 mixture, respectively, 2, 4, 7, 14, 30, and 60 days old, using both round and corrugated bars. Tests to show the effect of different conditions of storage were made upon specimens stored in sand, water, outside air, and air of laboratory.

In order to get the comparative quality of the concrete from each batch, compression cubes and cylinders were made. These cubes were 6-in. on the side and the cylinders were 8-in. in diameter and 16-in. long. In making the"mixture" specimens, three cubes and one cylinder were made from each of the different mixtures. In making the "time" specimens, three cubes were made from the first part of the batch, three from the middle portion, and three from the last. This was done on account of the size of the batch and the length of time required to make all of the specimens. In making the specimens for variation and size of bars, and storage specimens three cubes were made from each batch.

## II. AVAILABLE DATA.

1. Brief Discussion of Previous Tests and Their Results.

Under this head it will not be the object to give the actual data of previous tests, but merely to state their general results and conclusions. It has been found that the resistance offered by a steel rod imbedded in concrete consists of frictional resistance, adhesion, and shear. When the concrete sets, it contracts and grips the imbedded bar. This grip causes frictional resistance to any force tending to pull out the bar. The force of adhesion is probably slight, and its effect in producing bond cannot be determined. Shear is the resistance offered by the shearing of the concrete, and probably comprises the greater part of the bond in the patent deformed bars. The shear caused by the irregularity of surface of a plain round bar is probably very slight.

From tests made in 1906 by Mr. Todd Kirk of the civil engineering class, it was found that a rich mixture gives higher bond resistance than a lean one, that the length of imbedment of the bar makes very little difference in the bond resistance up to the point where the stretch of steel does not cause uneven distribution of the bond stress along the length of the bar, and that flat bars give much lower resistance than round ones. In general, it was decided that the value of the bond resistance depends upon the smoothness of the surface of the bar, the uniformity of its diameter

and section, the adhesive strength of the concrete, and the grip developed in setting.

## III. MATERIALS, TEST-PIECES, AND METHOD OF TESTING.

1. Materials.

In all of the tests made, the same kind and quality of cement, sand, and stone were used in making the specimens. The cement used was Chicago A-A portland. Results of tensile tests of this cement are given in Table IX. The sand was that known as torpedo sand, from Attica, Indiana, and was ordered screened through a 1/4-in. screen. The stone used was Kankakee limestone, and was ordered screened through a 1-in. screen and over a 1/4-in. screen. Table VIII shows the results of a number of tests to determine the fineness of the cement, sand, and stone. Tests were made to determine the per cent. of voids in the sand and stone, and the sand was found to contain about 28 per cent. of voids, and the stone about 50 per cent.

2. Test-pieces.

The form of test-piece used was a cylinder about 8 in. in diameter and 8 in. long, in the axis of which cylinder the steel reinforcing rod was placed. In making the test-pieces, two I-beams were set at the desired height, with their webs vertical and their inside flanges 2 or 3 in. apart. Flat iron plates were set upon the top flanges of these I-beams, and upon these were placed the circular galvanized iron forms, each form being kept from spreading by a circular iron band. The rods were placed inside these forms, their free ends between the I-beams, so that the

imbedded end of the rods projected 1/8 to 1/4 in. above the top of the forms. The concrete, after being mixed in the usual manner, great care being taken to secure a very thorough mixture, was put into the forms and carefully tamped. The specimens were allowed to remain in the forms for a period of 4 days, when the forms were removed and the specimens completely covered with damp sand. The compression cubes were treated in the same manner. The specimens which were tested for storage, were of course exceptions to this method of storage.

3. Method of Testing.

Previous to testing, all specimens more than 7days old were set up on an iron plate in plaster of paris. This was allowed to harden for a day or so, in order to provide an even bearing on the plate at the bottom of the test specimen when it rests in the machine. In testing the specimen, a bearing block was placed upon the head of the machine and an iron plate placed upon this block. A rubber cushion was put between this plate and the plate upon the bottom of the test-piece, which was placed with the free end down. This free end was caught in the lower grip of the machine and an initial load of about 100 lb. applied. The instrument which was used to show the slip of the rod in the concrete, was then clamped upon the top of the specimen and the dial set to read zero. A speed of 0.05 in.per minute was then started and the loads observed for the point of beginning of slip, for each 0.001 in. up to 0.005 in., for each 0.005 in. up to 0.030 in., and for each 0.010 in. from then

on until the rod had completely slipped, or the specimen had failed in some other way.

On the following page is given a photograph showing a specimen placed in the machine ready to be tested. The instrument by means of which the readings were taken, is shown clamped to the top of the specimen.

# TABLE NO. I.

Tests Showing Effect of Mixture Upon Bond Stress.

| No. of Specimen | Mixture | Max. Load lb. | Stress lb. per sq. in. Bond at Slip of 0.001 in. | At Max. Load | In Steel at Max. Load | Running Fric. | Slip at Max. Load in. |
|---|---|---|---|---|---|---|---|
| 202 | 1-4-8 | 5,370 | 173 | 283 | 12,100 | 210 | 0.025 |
| 203 | 1-4-8 | 5,100 | 200 | 270 | 11,600 | 210 | 0.020 |
| 204 | 1-4-8 | 4,270 | 145 | 226 | 9,700 | 130 | 0.025 |
| 205 | 1-4-8 | 5,150 | 161 | 273 | 11,700 | 220 | 0.040 |
| Average | | | 170 | 263 | | | |
| 206 | 1-3-6 | 6,950 | 268 | 368 | 15,800 | 240 | 0.020 |
| 207 | 1-3-6 | 6,440 | 242 | 341 | 14,600 | 240 | 0.025 |
| 209 | 1-3-6 | 6,660 | 227 | 353 | 15,100 | 240 | 0.025 |
| Average | | | 246 | 354 | | | |
| 221 | 1-2-4 | 7,730 | 295 | 410 | 17,500 | 290 | 0.015 |
| 222 | 1-2-4 | 5,310 | 215 | 282 | 12,100 | 210 | 0.010 |
| 223 | 1-2-4 | 5,260 | 194 | 278 | 11,900 | 240 | 0.025 |
| 224 | 1-2-4 | 8,240 | 282 | 437 | 18,700 | 320 | 0.025 |
| 225 | 1-2-4 | 7,200 | 299 | 382 | 16,300 | 240 | 0.010 |
| Average | | | 257 | 358 | | | |
| 211 | 1-1 1/2-3 | 8,460 | 277 | 447 | 19,200 | 260 | 0.020 |
| 212 | 1-1 1/2-3 | 8,640 | 285 | 457 | 19,400 | 320 | 0.030 |
| 213 | 1-1 1/2-3 | 7,630 | 313 | 404 | 17,300 | 230 | 0.025 |
| 214 | 1-1 1/2-3 | 9,370 | 313 | 495 | 21,200 | 370 | 0.040 |
| 215 | 1-1 1/2-3 | 7,590 | 294 | 402 | 17,200 | 260 | 0.030 |
| Average | | | 297 | 441 | | | |

TABLE NO. I. (Contd.)

| No. of Specimen | Mixture | Max. Load lb. | Stress lb. per sq. in. Bond at Slip of 0.001 in. | At Max. Load | In Steel at Max. Load | Running Fric. | Slip at Max. Load in. |
|---|---|---|---|---|---|---|---|
| 216 | 1-1-2 | 8,800 | 357 | 465 | 20,000 | 370 | 0.030 |
| 217 | 1-1-2 | 9,470 | 415 | 500 | 21,400 | 420 | 0.030 |
| 218 | 1-1-2 | 7,430 | 312 | 393 | 16,900 | 320 | 0.025 |
| 220 | 1-1-2 | 8,830 | 342 | 467 | 20,000 | 400 | 0.025 |
| Average | | | 356 | 456 | | | |

Note:-

Specimens used in above tests were 30 days old and contained 3/4-in. round rods. Area of rod = 0.442 sq. in. Surface in contact = 18.9 sq. in. Elastic limit of steel = 38,000 lb. per sq. in.

In all cases the failure was caused by the slipping of the rod.

# TABLE NO. II.

Tests Showing Effect of Storage Upon Bond Stress.

| No. of Spec-imen | Meth-od of Stor-age | Max. Load lb. | Stress lb. per sq. in. | | | | Slip at Max. Load in. |
|---|---|---|---|---|---|---|---|
| | | | Bond at Slip of 0.001 in. | At Max. Load | In Steel at Max. Load | Run-ning Fric. | |
| 301 | | 6,600 | 273 | 350 | 15,000 | 250 | 0.010 |
| 302 | In | 6,370 | 278 | 338 | 14,400 | 250 | 0.010 |
| 303 | water | 7,340 | 330 | 389 | 16,600 | 250 | 0.010 |
| 305 | | 6,620 | 297 | 352 | 15,000 | 250 | 0.015 |
| Average | | | 295 | 360 | | | |
| 306 | Open | 7,610 | 289 | 404 | 17,000 | 370 | 0.030 |
| 307 | air of | 8,140 | 334 | 432 | 18,400 | 380 | 0.020 |
| 308 | labor- | 7,200 | 285 | 382 | 16,300 | 350 | 0.030 |
| 309 | atory | 6,990 | 267 | 370 | 15,800 | 300 | 0.020 |
| 310 | | 7,380 | 308 | 392 | 16,700 | 320 | 0.015 |
| Average | | | 317 | 396 | | | |
| 311 | | 6,220 | 255 | 331 | 14,100 | 280 | 0.015 |
| 312 | Out- | 6,820 | 277 | 362 | 15,500 | 260 | 0.015 |
| 313 | side | 7,380 | 265 | 392 | 16,700 | 340 | 0.015 |
| 314 | air | 7,000 | 287 | 372 | 15,900 | 320 | 0.020 |
| 315 | | 6,870 | 273 | 364 | 15,500 | 320 | 0.020 |
| Average | | | 271 | 364 | | | |
| 316 | | 5,040 | 227 | 268 | 11,400 | 180 | 0.010 |
| 317 | Damp | 4,850 | 117 | 257 | 11,000 | 210 | 0.020 |
| 319 | | 6,130 | 263 | 325 | 13,900 | 240 | 0.015 |
| 320 | sand | 6,760 | 284 | 358 | 15,300 | 270 | 0.015 |
| 321 | | 7,120 | 308 | 378 | 16,100 | 300 | 0.015 |
| Average | | | 240 | 354 | | | |

TABLE NO. II. (Contd.)

Note:--

Specimens used in above tests were made from 1-2-4 concrete and contained 3/4-in. round rods. Age 30 days. Elastic limit of steel = 38,000 lb. per sq. in. Area of rod = 0.442 sq. in. Surface in contact = 18.9 sq. in.

In all cases the failure was caused by the slipping of the rod.

# TABLE NO. III.

Tests Showing Effect of Variations in Size of Round Rods Upon Bond Stress.

| No. of Specimen | Diam. of Rod in. | Max. Load lb. | Stress lb. per sq. in. | | | | Slip at Max. Load in. |
|---|---|---|---|---|---|---|---|
| | | | Bond at Slip of 0.001 in. | At Max. Load | In Steel at Max. Load | Running Fric. | |
| 251 | 1/2 | 6,530 | 398 | 520 | 33,200 | 350 | 0.015 |
| 253 | 1/2 | 5,480 | 351 | 436 | 27,800 | 270 | 0.010 |
| 254 | 1/2 | 6,060 | 369 | 482 | 30,800 | 350 | 0.015 |
| 255 | 1/2 | 6,100 | 392 | 485 | 31,000 | 300 | 0.010 |
| Average | | | 378 | 481 | | | |
| 256 | 5/8 | 7,160 | 368 | 457 | 23,300 | 320 | 0.015 |
| 257 | 5/8 | 6,770 | 350 | 432 | 22,000 | 300 | 0.010 |
| 258 | 5/8 | 9,420 | 498 | 601 | 30,700 | 300 | 0.010 |
| 260 | 5/8 | 6,120 | 328 | 390 | 19,900 | 400 | 0.015 |
| Average | | | 386 | 446 | | | |
| 221 | 3/4 | 7,730 | 295 | 410 | 17,500 | 290 | 0.015 |
| 222 | 3/4 | 5,310 | 215 | 282 | 12,000 | 210 | 0.010 |
| 223 | 3/4 | 6,260 | 194 | 278 | 14,200 | 240 | 0.025 |
| 224 | 3/4 | 8,240 | 282 | 437 | 18,700 | 320 | 0.025 |
| 225 | 3/4 | 7,200 | 299 | 382 | 16,300 | 240 | 0.010 |
| Average | | | 257 | 360 | | | |
| 262 | 1 | 13,020 | 393 | 518 | 16,600 | 370 | 0.020 |
| 263 | 1 | 12,900 | 417 | 513 | 16,500 | 400 | 0.020 |
| 264 | 1 | 14,000 | 432 | 560 | 17,900 | 420 | 0.015 |
| 265 | 1 | 9,720 | 290 | 387 | 12,400 | 300 | 0.020 |
| Average | | | 383 | 495 | | | |

TABLE NO. III. (Contd.)

| No. of Specimen | Diam. of Rod in. | Max. Load lb. | Stress lb. per sq. in. Bond at Slip of 0.001 in. | At Max. Load | In Steel at Max. Load | Running Fric. | Slip at Max. Load in. |
|---|---|---|---|---|---|---|---|
| 266 | 1 1/4 | 12,400 | 268 | 395 | 10,100 | 400 | 0.020 |
| 267 | 1 1/4 | 12,690 | 306 | 403 | 10,300 | 350 | 0.015 |
| 268 | 1 1/4 | 15,590 | 320 | 495 | 12,700 | 330 | 0.015 |
| 269 | 1 1/4 | 17,000 | 365 | 540 | 13,800 | 300 | 0.015 |
| 270 | 1 1/4 | 14,000 | 328 | 445 | 11,400 | 300 | 0.020 |
| Average | | | 317 | 456 | | | |

APPENDIX TO TABLE III.

| Diameter of Rod in. | Area of Rod sq. in. | Surface in Contact sq. in. |
|---|---|---|
| 1/2 | 0.197 | 12.6 |
| 5/8 | 0.308 | 15.7 |
| 3/4 | 0.442 | 18.9 |
| 1 | 0.786 | 25.2 |
| 1 1/4 | 1.230 | 31.5 |

Note:-

Specimens used in the above tests were 30 days old and were made of 1-2-4 concrete. Elastic limit of steel = 38,000 lb. per sq. in.

In all cases the failure was caused by the slipping of the rod.

## TABLE NO. IV.

Tests Showing Effect of Age of Specimen Upon

Bond Stress.

| No. of Specimen | Age in Days | Max. Load lb. | Stress lb. per sq. in. Bond at Slip of 0.001 in. | At Max. Load | In Steel at Max. Load | Running Fric. | Slip at Max. Load in. |
|---|---|---|---|---|---|---|---|
| 101 | 2 | 1,150 | 41 | 61 | 2,600 | 50 | 0.015 |
| 103 | 2 | 1,490 | 44 | 79 | 3,380 | 80 | 0.025 |
| 104 | 2 | 1,120 | 37 | 59 | 2,550 | 80 | 0.015 |
| 105 | 2 | 1,000 | 47 | 53 | 2,270 | 50 | 0.010 |
| Average | | | 42 | 63 | | | |
| 111 | 4 | 3,200 | 90 | 169 | 7,250 | 130 | 0.015 |
| 112 | 4 | 2,400 | 88 | 127 | 5,450 | 100 | 0.015 |
| 113 | 4 | 2,690 | 92 | 142 | 6,100 | 120 | 0.020 |
| 114 | 4 | 2,290 | 90 | 121 | 5,200 | 70 | 0.010 |
| 115 | 4 | 2,510 | 93 | 133 | 5,700 | 100 | 0.015 |
| Average | | | 91 | 138 | | | |
| 121 | 7 | 3,610 | 109 | 192 | 8,200 | 130 | 0.020 |
| 122 | 7 | 2,750 | 88 | 145 | 6,240 | 100 | 0.015 |
| 123 | 7 | 2,760 | 86 | 146 | 6,280 | 100 | 0.020 |
| 124 | 7 | 4,290 | 143 | 227 | 9,760 | 180 | 0.025 |
| 125 | 7 | 2,570 | 105 | 136 | 5,820 | 100 | 0.010 |
| Average | | | 106 | 169 | | | |
| 131 | 14 | 4,110 | 178 | 217 | 9,320 | 150 | 0.015 |
| 132 | 14 | 6,100 | 202 | 322 | 13,850 | 250 | 0.020 |
| 133 | 14 | 5,130 | 170 | 272 | 11,600 | 220 | 0.020 |
| 134 | 14 | 5,740 | 207 | 304 | 13,000 | 240 | 0.025 |
| 135 | 14 | 4,170 | 162 | 221 | 9,460 | 150 | 0.015 |
| Average | | | 184 | 267 | | | |

TABLE NO. IV. (Contd.)

| No. of Specimen | Age in Days | Max. Load lb. | Stress lb. per sq. in. Bond at Slip of 0.001 in. | At Max. Load | In Steel at Max. Load | Running Fric. | Slip at Max. Load in. |
|---|---|---|---|---|---|---|---|
| 141 | 30 | 7,730 | 295 | 410 | 17,600 | 300 | 0.015 |
| 142 | 30 | 5,310 | 215 | 282 | 12,100 | 200 | 0.010 |
| 143 | 30 | 5,260 | 194 | 278 | 11,900 | 230 | 0.025 |
| 144 | 30 | 8,240 | 282 | 437 | 18,700 | 320 | 0.025 |
| 145 | 30 | 7,200 | 299 | 382 | 16,300 | 200 | 0.010 |
| Average | | | 257 | 360 | | | |
| 151 | 60 | 12,040 | 492 | 638 | 25,000 | 450 | 0.015 |
| 152 | 60 | 12,310 | 485 | 651 | 28,000 | 450 | 0.015 |
| 153 | 60 | 11,070 | 405 | 585 | 25,000 | 400 | 0.015 |
| 154 | 60 | 7,560 | 307 | 400 | 17,200 | 300 | 0.020 |
| Average | | | 422 | 568 | | | |

Note:-

Specimens used in the above test were made of 1-2-4 concrete and contained 3/4-in. round rods. Area of rod = 0.442 sq. in. Surface in contact = 18.9 sq. in. Elastic limit of steel = 38,000 lb. per sq. in.

In all cases the failure was caused by the slipping of the rod.

# TABLE NO. V.

Tests Showing Effect of Age of Specimen Upon

Bond Stress.

| No. of Specimen | Age in Days | Max. Load lb. | Stress lb. per sq. in. Bond at Slip of 0.001 in. | At Max. Load | In Steel at Max. Load | Running Fric. | Slip at Max. Load in. |
|---|---|---|---|---|---|---|---|
| 106 | 2 | 1,510 | 35 | 95 | 6,050 | 70 | 0.050 |
| 107 | 2 | 1,370 | 36 | 86 | 5,500 | 70 | 0.050 |
| 108 | 2 | 1,560 | 54 | 98 | 6,250 | 70 | 0.030 |
| 109 | 2 | 2,190 | 48 | 138 | 8,780 | 100 | 0.025 |
| 110 | 2 | 1,930 | 58 | 121 | 7,700 | 70 | 0.020 |
| Average | | | 46 | 107 | | | |
| 116 | 4 | 4,200 | 102 | 263 | 16,800 | 200 | 0.040 |
| 117 | 4 | 3,310 | 85 | 208 | 13,200 | 110 | 0.030 |
| 118 | 4 | 3,670 | 104 | 230 | 14,700 | 200 | 0.040 |
| 119 | 4 | 3,430 | 101 | 215 | 13,700 | 200 | 0.050 |
| 120 | 4 | 3,500 | 78 | 219 | 14,000 | 200 | 0.060 |
| Average | | | 94 | 227 | | | |
| 127 | 7 | 4,490 | 121 | 281 | 17,900 | 220 | 0.050 |
| 128 | 7 | 3,870 | 119 | 242 | 15,500 | 180 | 0.025 |
| 129 | 7 | 4,670 | 124 | 294 | 18,300 | 250 | 0.040 |
| 130 | 7 | 5,240 | 129 | 328 | 21,000 | 280 | 0.040 |
| Average | | | 123 | 286 | | | |
| 138 | 14 | 6,960 | 273 | 435 | 27,800 | 200 | 0.020 |
| 139 | 14 | 8,000 | 218 | 500 | 32,000 | 400 | 0.050 |
| 140 | 14 | 7,550 | 227 | 472 | 30,200 | 400 | 0.030 |
| Average | | | 239 | 469 | | | |

TABLE NO. V. (Contd.)

| No. of Specimen | Age in Days | Max. Load lb. | Stress lb. per sq. in. Bond at Slip of 0.001 in. | At Max. Load | In Steel at Max. Load | Running Fric. | Slip at Max. Load in. |
|---|---|---|---|---|---|---|---|
| 146 | 30 | 10,390 | 283 | 650 | 41,500 | 600 | 0.110 |
| 147 | 30 | 9,460 | 325 | 592 | 37,800 | 600 | 0.080 |
| 148 | 30 | 10,210 | 366 | 652 | 41,000 | 600 | 0.100 |
| 149 | 30 | 10,520 | 313 | 659 | 42,000 | 600 | 0.100 |
| 150 | 30 | 10,650 | 287 | 667 | 42,600 | 600 | 0.120 |
| Average | | | 315 | 644 | | | |
| 156 | 60 | 26,000 | 610 | 1,086 | 46,300 | | 0.015 |
| 157 | 60 | 17,000 | 522 | 708 | 30,300 | | 0.010 |
| 158 | 60 | 25,000 | 518 | 1,042 | 44,500 | | 0.025 |
| 159 | 60 | 21,720 | 395 | 908 | 38,500 | | 0.030 |
| Average | | | 511 | 937 | | | |

Note:-

Specimens in the above tests were made of 1-2-4 concrete and contained 1/2-in.corrugated bars, with the exception of the 60 day specimens which contained 3/4-in. rods. Area of 1/2-in. rod = 0.25 sq. in. Surface in contact = 16.0 sq. in. Elastic limit of steel = 55,000 lb.per sq. in. Area of 3/4-in. rod = 0.562 sq. in. Surface in contact = 24.0 sq. in. Elastic limit of steel = 53,500 lb. per sq. in.

In all cases the failure was caused by the splitting of the concrete.

TABLE NO. VI.

Summary of Tests.

| No. of Tests | Mixture | Method of Storage | Form and Size of Bar | Age of Specimen at Time of Test Days | Average Max. Bond Stress lb. per sq. in. | Percent Increase over Preceding Set of Tests | Percent Increase over 1-4-8 Mixture |
|---|---|---|---|---|---|---|---|
| | | | Variation in Mixture. | | | | |
| 4 | 1-4-8 | | | 30 | 263 | | |
| 4 | 1-3-6 | Damp | 3/4-in. | 30 | 303 | 15 | 15 |
| 5 | 1-2-4 | | | 30 | 360 | 18 | 36 |
| | | sand | round | | | | |
| 5 | 1-1 1/2-3 | | | 30 | 441 | 23 | 68 |
| 4 | 1-1-2 | | | 30 | 456 | 3 | 74 |
| | | | Variation in Method of Storage. | | | | |
| 4 | 1-2-4 | Water | | 30 | 357 | | |
| 5 | 1-2-4 | Air of lab. | 3/4-in. | 30 | 396 | | |
| 5 | 1-2-4 | Outside air. | | 30 | 364 | | |
| 5 | 1-2-4 | Damp sand. | round | 30 | 354 | | |
| | | | Variation in Size of Bar. | | | | |
| 4 | 1-2-4 | | 1/2-in. round | 30 | 481 | | |
| 4 | 1-2-4 | Damp | 5/8-in. round | 30 | 446 | | |
| 5 | 1-2-4 | | 3/4-in. round | 30 | 360 | | |
| 4 | 1-2-4 | sand | 1-in. round | 30 | 494 | | |
| 5 | 1-2-4 | | 1 1/4-in. round | 30 | 456 | | |

TABLE NO. VI. ( Contd.)

| No. of Tests | Mixture | Method of Storage | Form and Size of Bar | Age of Specimen at Time of Test Days | Average Max. Bond Stress lb. per sq. in. | Percent Increase over Preceding Set of Tests | Percent Increase over 2 day Tests |
|---|---|---|---|---|---|---|---|
| | | | Variation in Age of Concrete. | | | | |
| 3 | 1-2-4 | | | 2 | 63 | | |
| 5 | 1-2-4 | Damp | 3/4-in. | 4 | 138 | 119 | 119 |
| 5 | 1-2-4 | | | 7 | 169 | 23 | 169 |
| 5 | 1-2-4 | sand | round | 14 | 267 | 58 | 324 |
| 5 | 1-2-4 | | | 30 | 360 | 34 | 468 |
| 4 | 1-2-4 | | | 60 | 568 | 59 | 800 |
| | | | | | | | |
| 4 | 1-2-4 | | | 2 | 107 | | |
| 5 | 1-2-4 | Damp | 1/2-in. | 4 | 227 | 75 | 75 |
| 4 | 1-2-4 | | | 7 | 286 | 26 | 167 |
| 3 | 1-2-4 | sand | corru- | 14 | 469 | 64 | 338 |
| 4 | 1-2-4 | | gated | 30 | 644 | 37 | 500 |
| 4 | 1-2-4 | | 3/4-in. corrug. | 60 | 937 | 46 | 778 |

## TABLE NO. VII.

Cube and Cylinder Tests Made in Connection with Bond Tests.

| No. of Specimen | Mixture | Max. Load | Unit Load lb. per sq. in. | Average Unit Load lb. per sq. in. | Remarks |
|---|---|---|---|---|---|
| 201 | 1-4-8 | 21,500 | 430 | | |
| 206 | 1-3-6 | 24,100 | 480 | | |
| 211 | 1-1 1/2-3 | 63,200 | 1,260 | | |
| 216 | 1-1-2 | 116,500 | 2,320 | | These specimens made from batch of concrete from which specimens for "mixture" were made. All specimens tested at 30 days. |
| 201-1 | 1-4-8 | 31,700 | 880 | | |
| 201-2 | 1-4-8 | 33,200 | 922 | 909 | |
| 201-3 | 1-4-8 | 33,250 | 924 | | |
| 206-1 | 1-3-6 | 33,450 | 930 | | |
| 206-2 | 1-3-6 | 32,200 | 895 | 895 | |
| 206-3 | 1-3-6 | 30,900 | 860 | | |
| 211-1 | 1-1 1/2-3 | 67,400 | 1,870 | | |
| 211-2 | 1-1 1/2-3 | 62,800 | 1,742 | 1,812 | |
| 211-3 | 1-1 1/2-3 | 66,800 | 1,825 | | |
| 216-1 | 1-1-2 | 98,800 | 2,740 | | |
| 216-2 | 1-1-2 | 85,600 | 2,380 | 2,617 | |
| 216-3 | 1-1-2 | 94,700 | 2,730 | | |

Note:-

Specimens 201, 206, 211, and 216 were cylinders, the remaining specimens were cubes.

TABLE NO. VII. (Contd.)

| No. of Specimen | Max. Load | Unit Load lb. per sq. in. | Average Unit Load lb. per sq. in. | Remarks |
|---|---|---|---|---|
| Cubes made from the same batch of concrete as "time" specimens. | | | | |
| 100-1 | 51,200 | 1,420 | | |
| 100-1 | 49,400 | 1,370 | 1,370 | From first part of batch. |
| 100-1 | 47,600 | 1,320 | | |
| 100-2 | 50,000 | 1,390 | | |
| 100-2 | 57,300 | 1,590 | 1,507 | From middle portion of batch. |
| 100-2 | 55,500 | 1,540 | | |
| 100-3 | 53,700 | 1,490 | | |
| 100-3 | 56,100 | 1,560 | 1,540 | From last of batch. |
| 100-3 | 56,500 | 1,500 | | |
| Cubes made from same batch of concrete as "storage" specimens. | | | | |
| 300-1 | 51,700 | 1,435 | | |
| 300-2 | 57,700 | 1,600 | 1,432 | |
| 300-3 | 45,400 | 1,260 | | |
| Cubes made from same batch of concrete as "size" of bar specimens. | | | | |
| 250-1 | 44,600 | 1,240 | | |
| 250-2 | 49,600 | 1,380 | 1,263 | |
| 250-3 | 42,000 | 1,170 | | |

## TABLE NO. VIII.

Fineness of Chicago A. A. Cement.

| Test No. | Percent passing seive No. 75 | 100 | 200 |
|---|---|---|---|
| 1 | 99.3 | 98.5 | 90.1 |
| 2 | 98.5 | 95.6 | 81.5 |
| 3 | 98.0 | 94.5 | 79.7 |
| Average | 98.6 | 96.2 | 83.7 |

Fineness of Torpedo Sand.

Percent passing seive No.

| 3 | 5 | 10 | 12 | 16 | 18 | 30 | 40 | 50 | 74 | 150 |
|---|---|---|---|---|---|---|---|---|---|---|
| 99.2 | 89.0 | 64.7 | 57.8 | 49.9 | 39.0 | 21.6 | 11.8 | 5.1 | 2.6 | 0.46 |

Note:-
These values are the averages of 21 tests from samples taken at intervals throughout the season.

Fineness of Kankakee Limestone.

Percent passing seive No.

| 1-in. | 3/4-in. | 1/2-in. | 3/8-in. | 3 | 5 | 10 |
|---|---|---|---|---|---|---|
| 100 | 89.2 | 54.7 | 32.8 | 16.9 | 4.1 | 2.5 |

Note:-
These values are the averages of 8 tests from samples taken at intervals throughout the season.

## TABLE NO. IX.

Tensile Strength of Chicago A. A. Cement.

| Ref. No. | Tensile strength lb. per sq. in. | | | |
|---|---|---|---|---|
| | Age 7 days | | Age 28 days | |
| | neat | 1-3 | neat | 1-3 |
| 1 | 559 | 145 | 707 | 247 |
| 2 | 732 | 205 | 857 | 318 |
| 3 | 665 | 175 | 779 | 266 |
| 4 | 811 | 227 | 833 | 307 |
| 5 | 666 | 182 | 792 | 284 |
| Average | 686 | 184 | 794 | 284 |

Note:-
Each value given is average of tests from 5 briquettes.

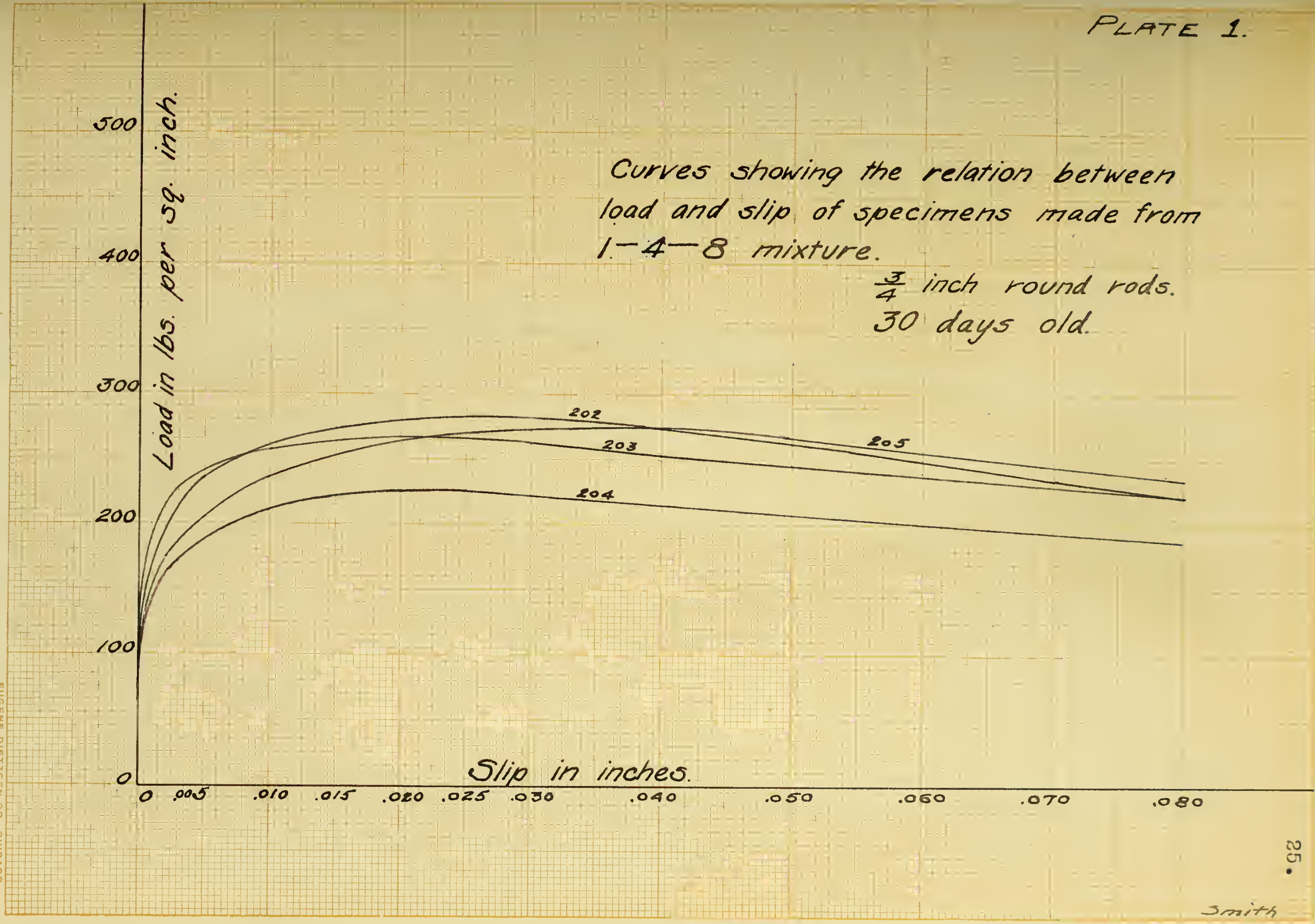


PLATE 1.
Curves showing the relation between load and slip of specimens made from 1-4-8 mixture.
$\frac{3}{4}$ inch round rods.
30 days old.
Load in lbs. per sq. inch.
Slip in inches.
500
400
300
200
100
0
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
202
203
204
205
Smith

PLATE 2.

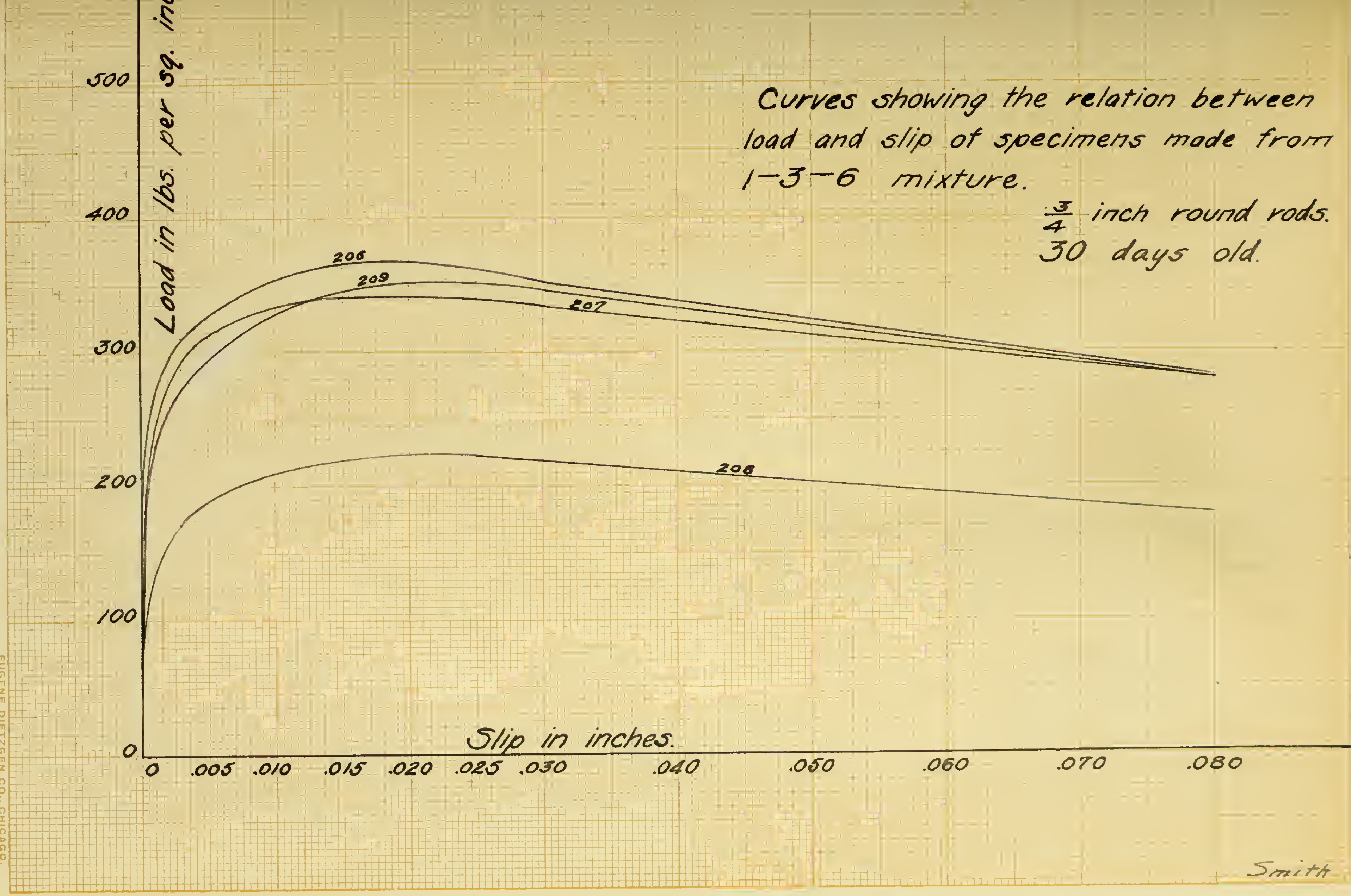

Curves showing the relation between load and slip of specimens made from 1-3-6 mixture.
3/4 inch round rods.
30 days old.
Load in lbs. per sq. inch.
500
400
300
200
100
0
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
206
209
207
208
Smith
EUGENE DIETZGEN CO., CHICAGO.

PLATE 3.

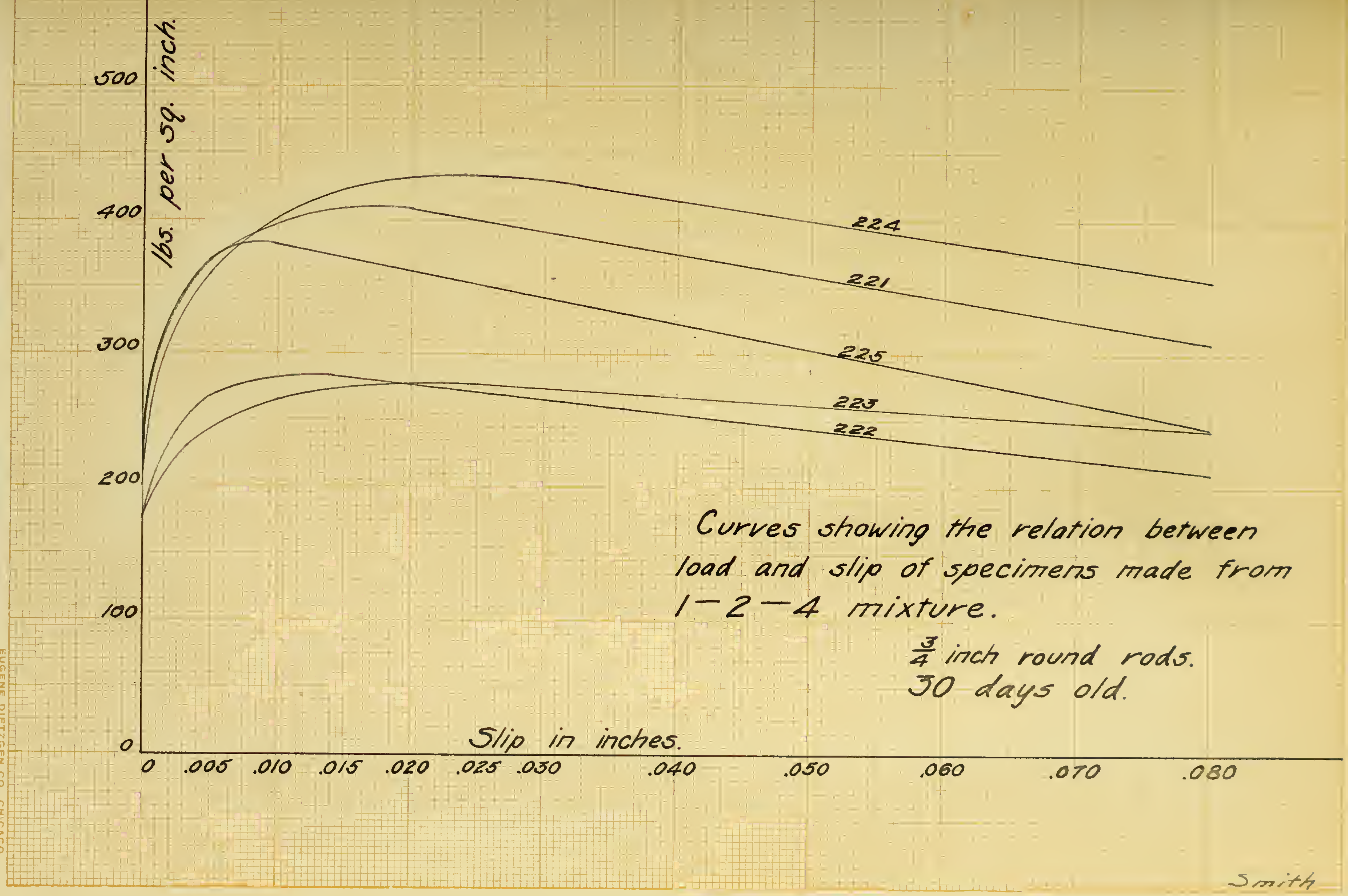
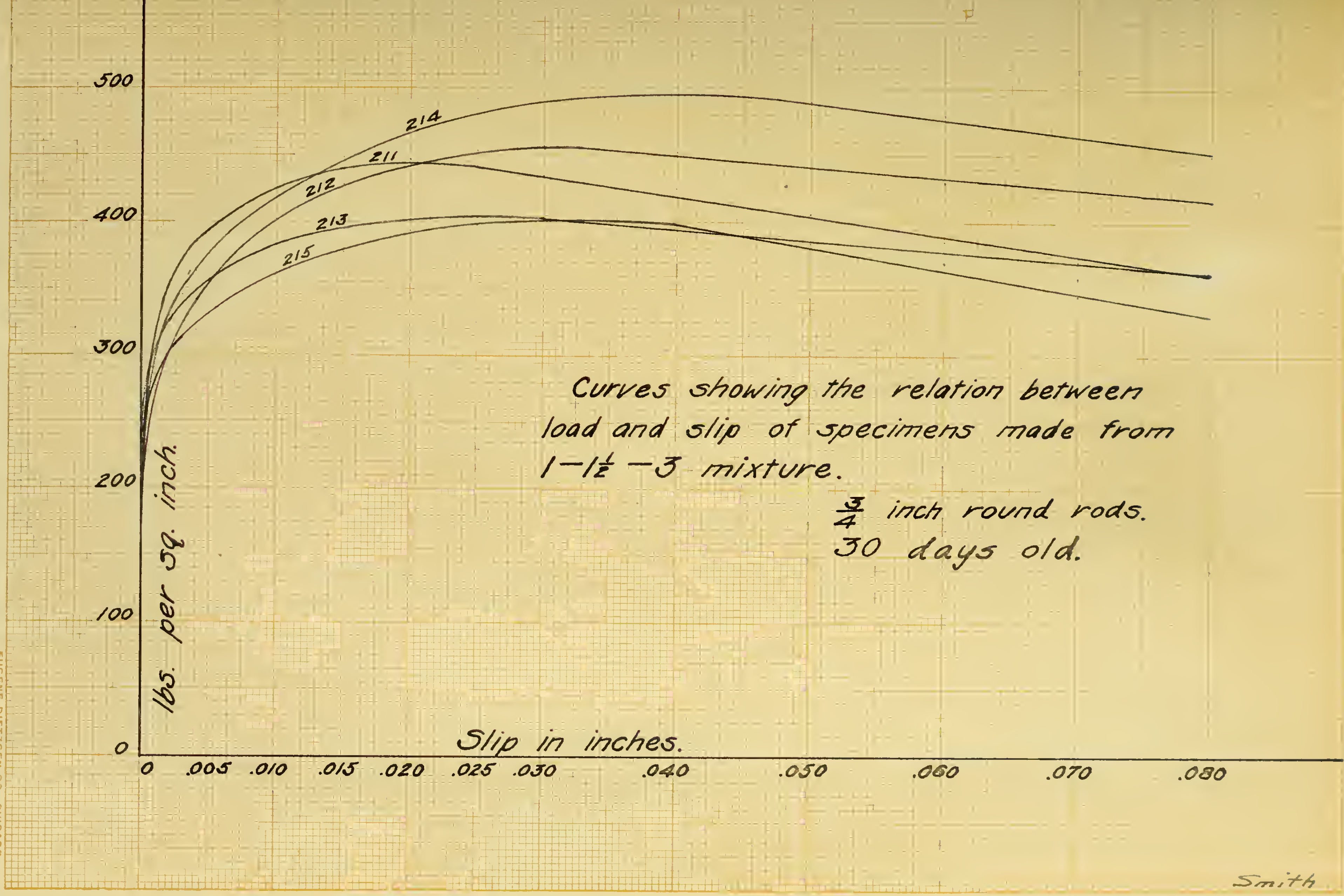
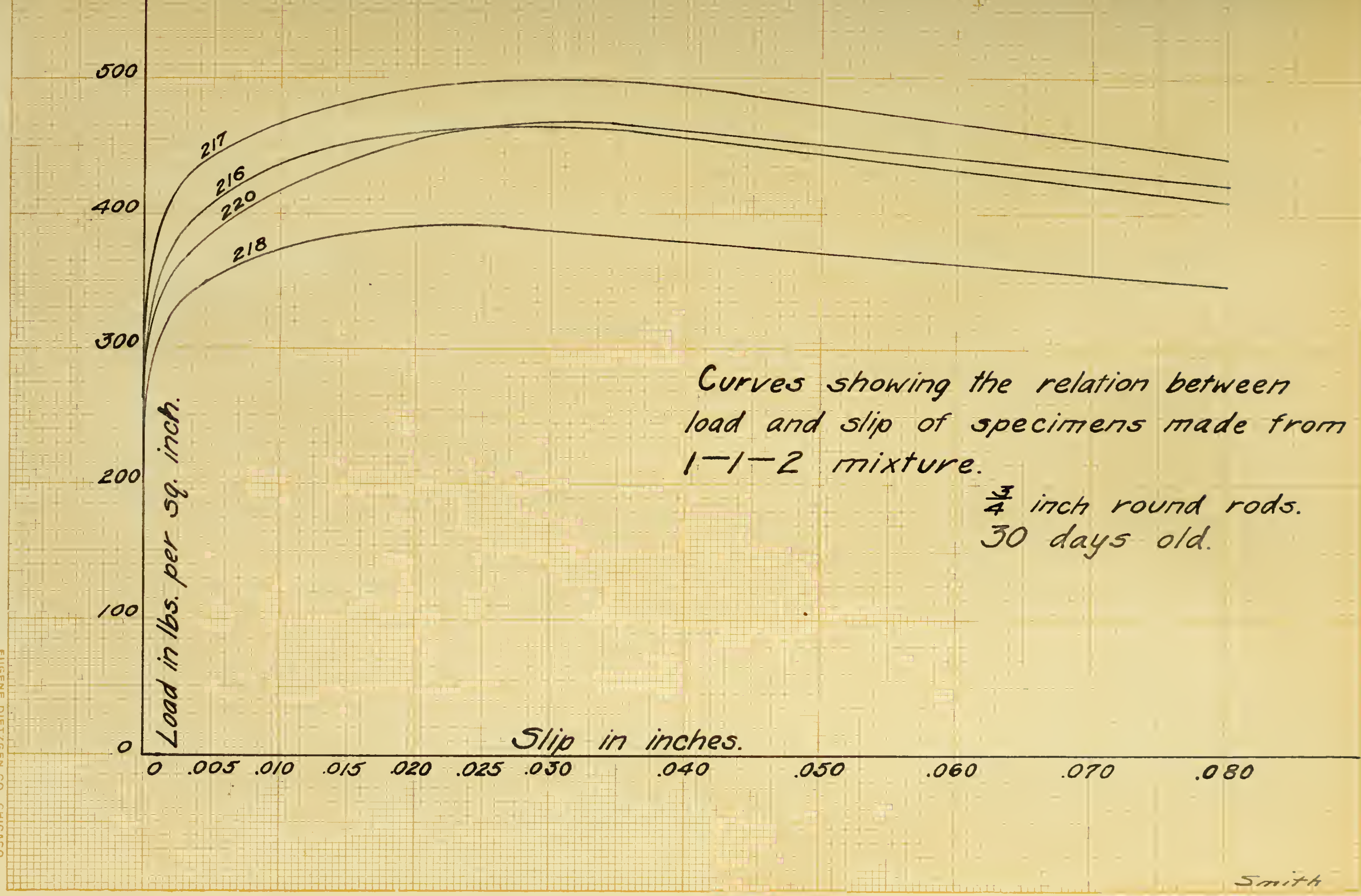

lbs. per sq. inch.
500
400
300
200
100
0
224
221
225
223
222
Curves showing the relation between load and slip of specimens made from 1—2—4 mixture.
$\frac{3}{4}$ inch round rods.
30 days old.
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
Smith
EUGENE DIETZGEN CO., CHICAGO.

PLATE 4.



Curves showing the relation between load and slip of specimens made from 1–1½–3 mixture.
¾ inch round rods.
30 days old.
lbs. per sq. inch.
Slip in inches.
500
400
300
200
100
0
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
214
211
212
213
215
Smith
EUGENE DIETZGEN CO., CHICAGO.

PLATE 5.



Curves showing the relation between load and slip of specimens made from 1-1-2 mixture.
$\frac{3}{4}$ inch round rods.
30 days old.
Load in lbs. per sq. inch.
Slip in inches.
0
100
200
300
400
500
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
217
216
220
218
Smith
EUGENE DIETZGEN CO., CHICAGO.

PLATE 6.

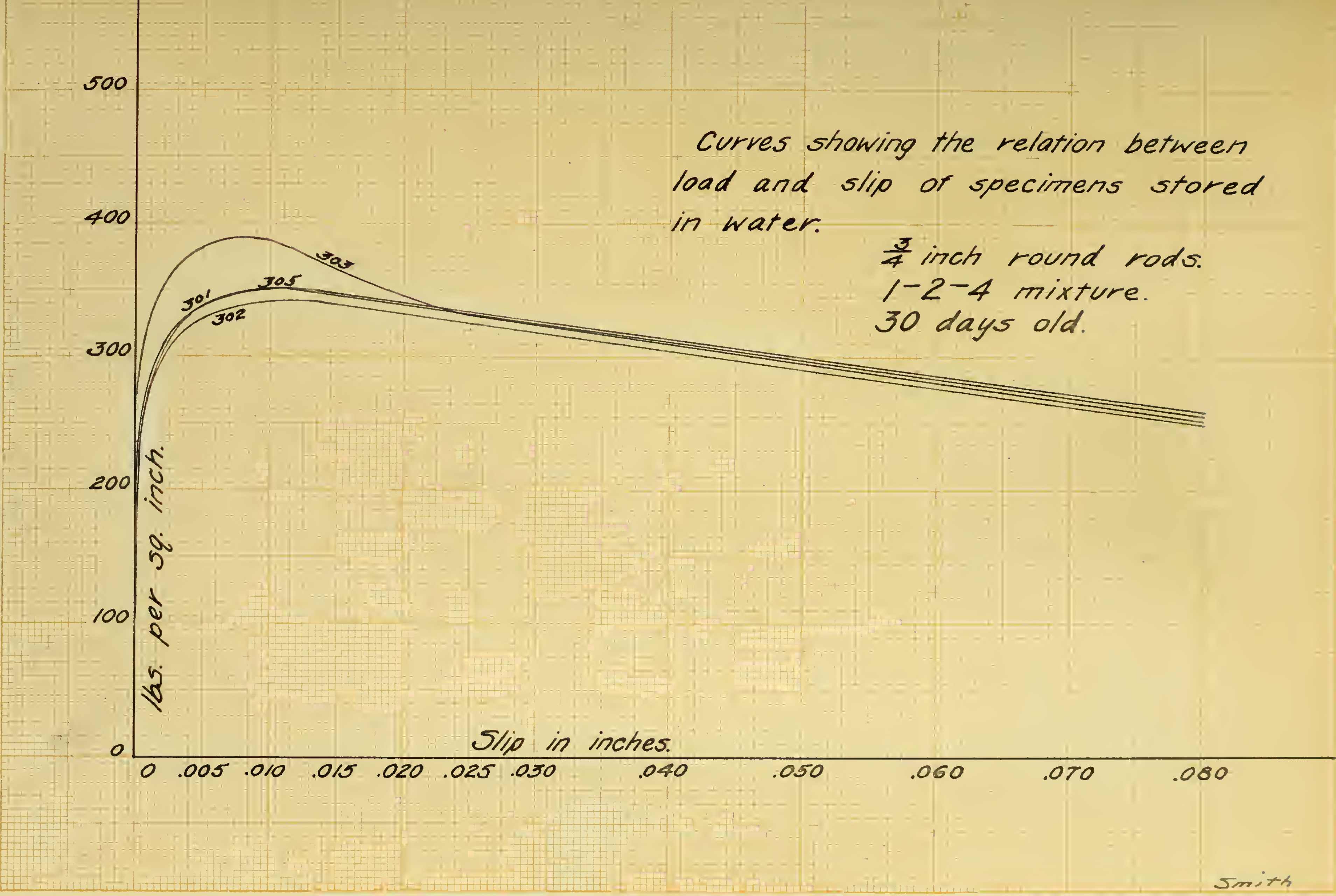
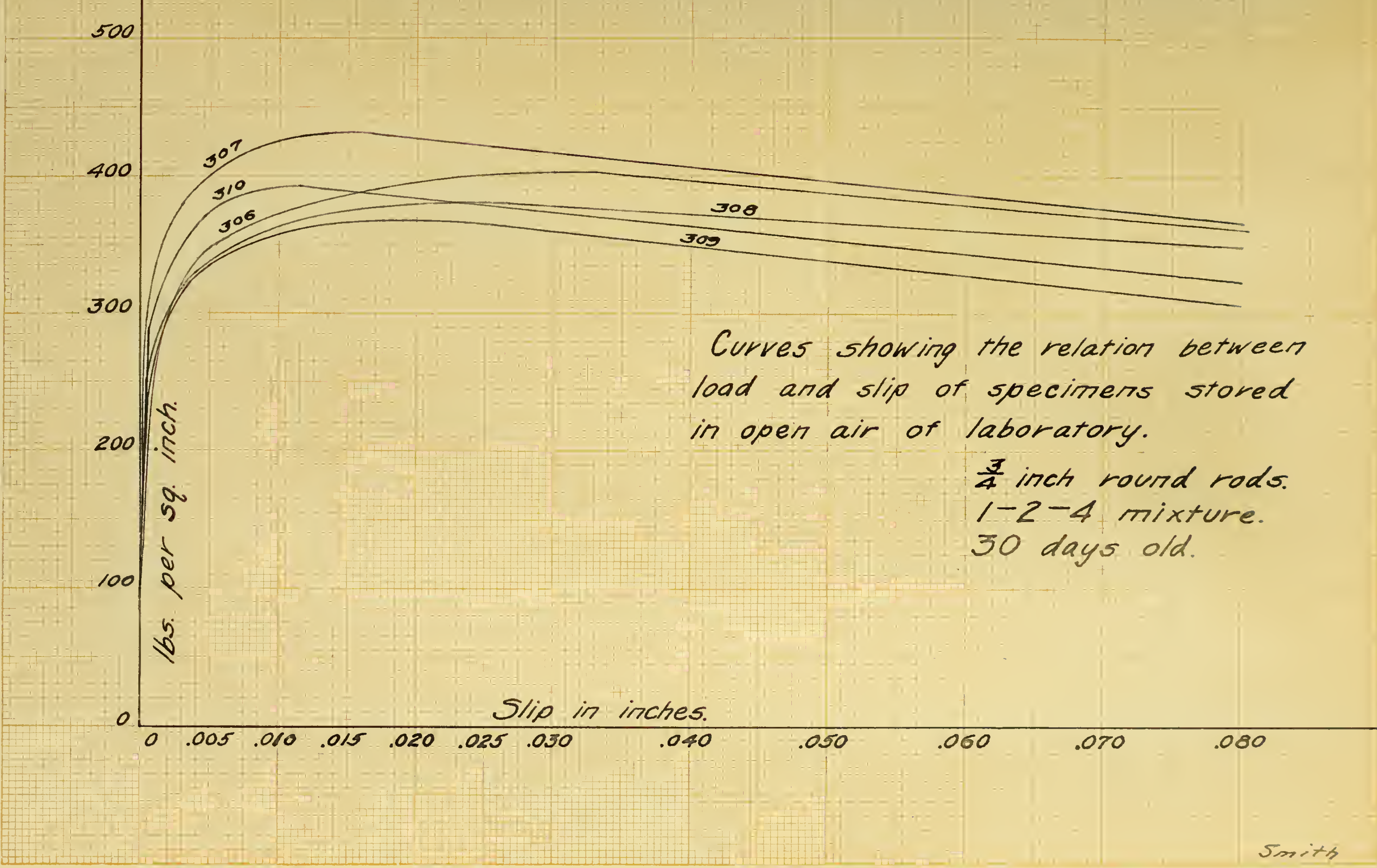
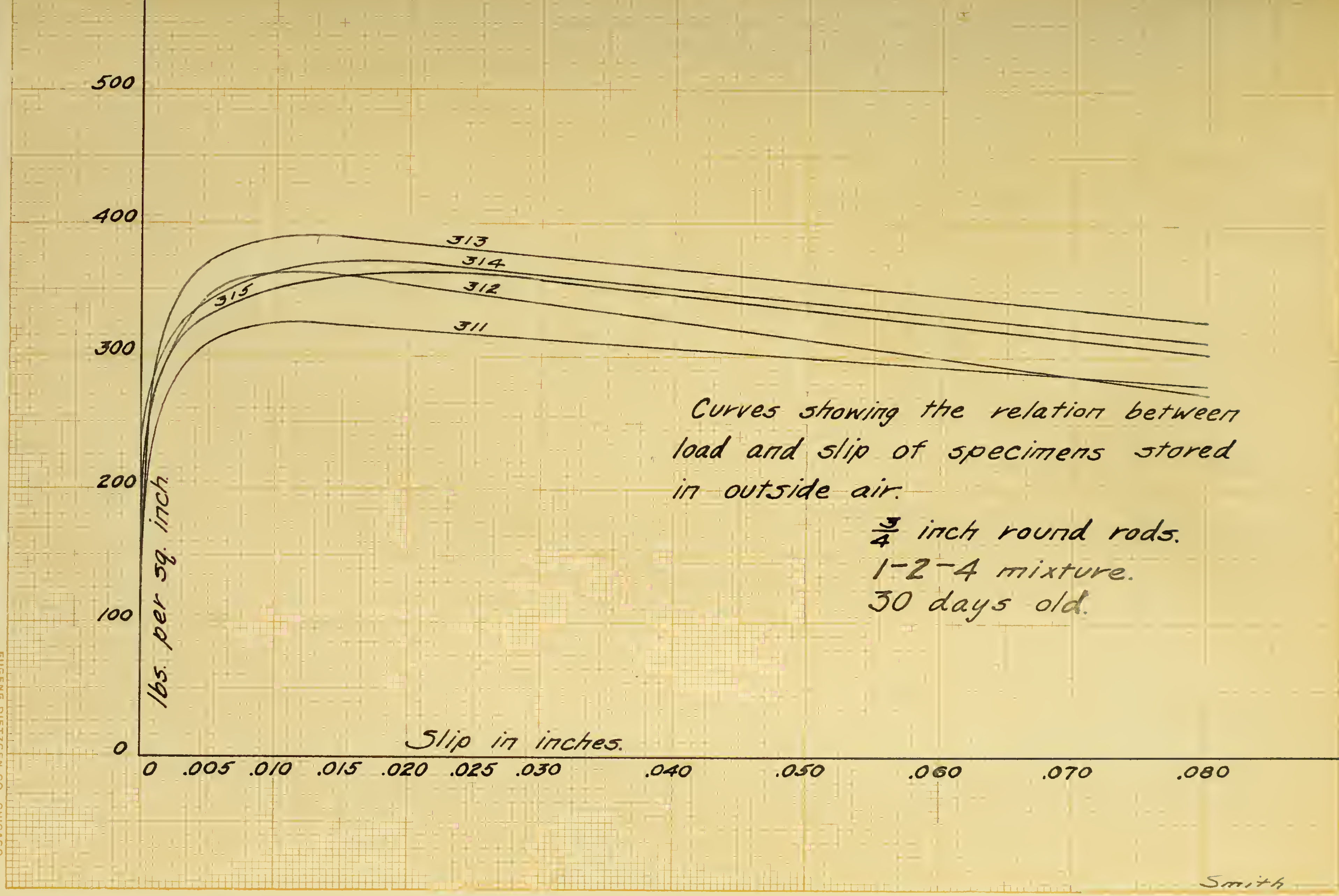

Curves showing the relation between load and slip of specimens stored in water.
$\frac{3}{4}$ inch round rods.
1-2-4 mixture.
30 days old.
303
305
301
302
500
400
300
200
100
0
lbs. per sq. inch.
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
Smith

PLATE 7.




Smith

# PLATE 8.



500
400
300
200
100
0
lbs. per sq. inch
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
Slip in inches.
313
314
315
312
311
Curves showing the relation between load and slip of specimens stored in outside air.
$\frac{3}{4}$ inch round rods.
1-2-4 mixture.
30 days old.
Smith

# PLATE 9.

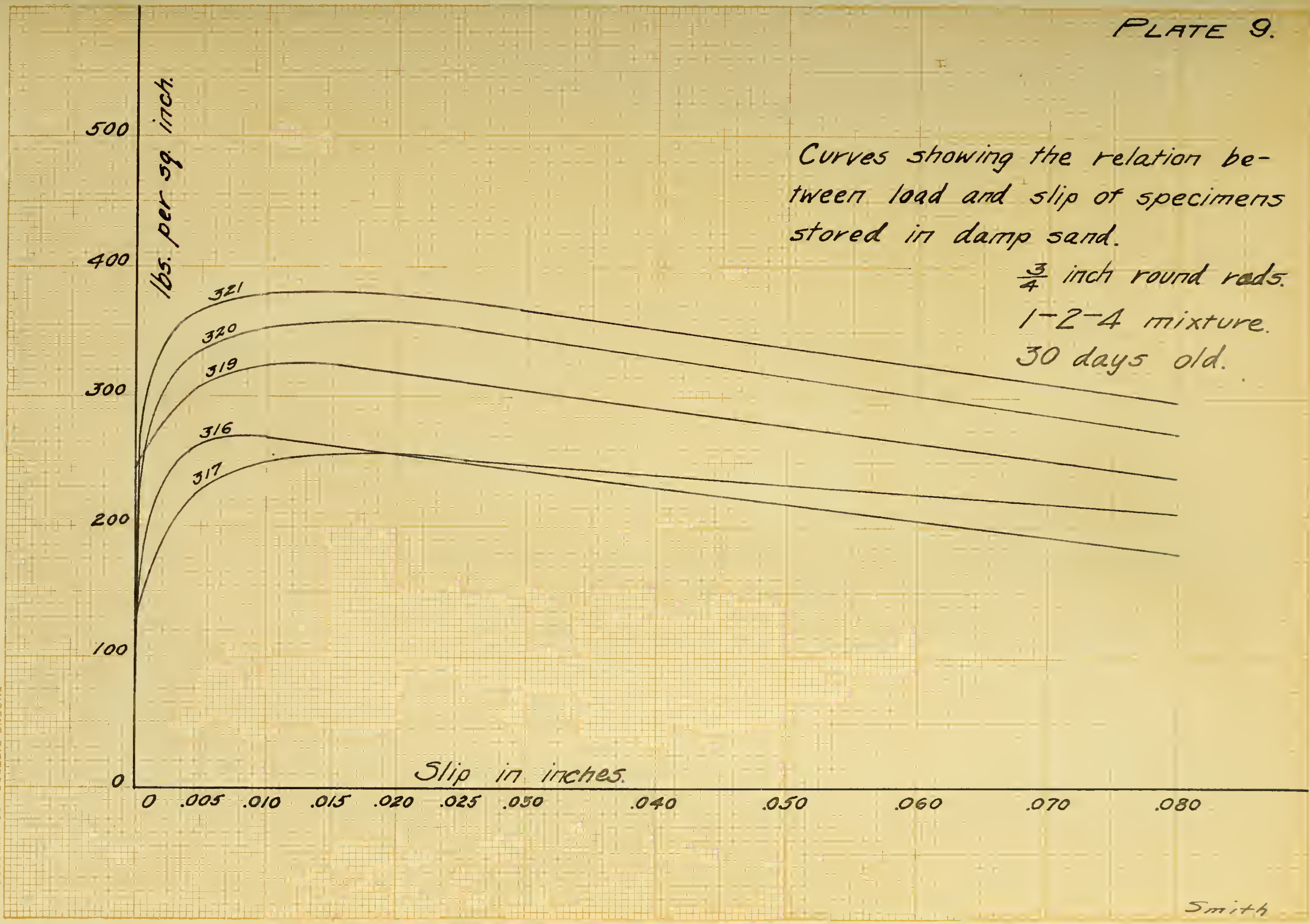
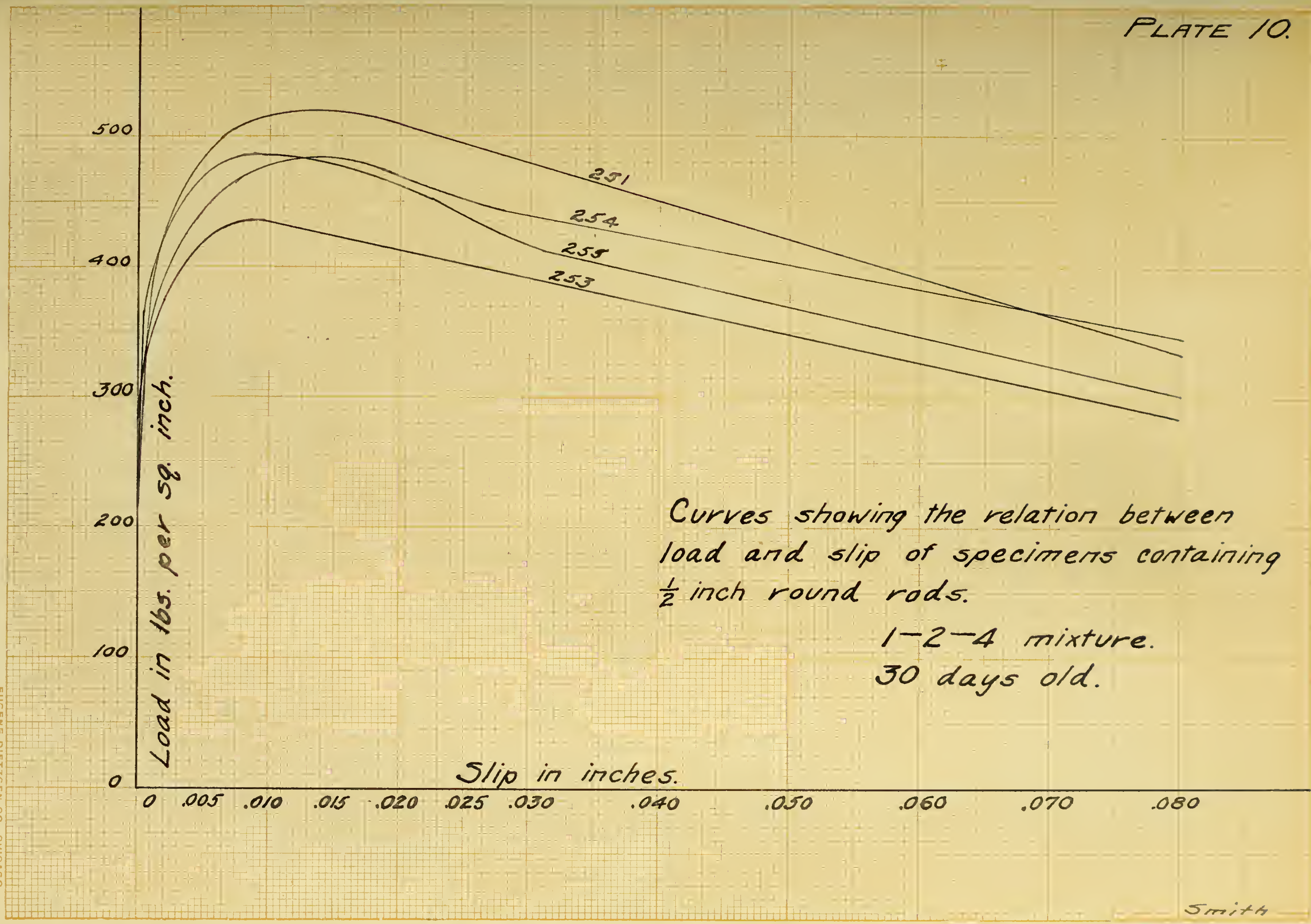

Curves showing the relation between load and slip of specimens stored in damp sand.
$\frac{3}{4}$ inch round rods.
1-2-4 mixture.
30 days old.
lbs. per sq. inch.
500
400
300
200
100
0
321
320
319
316
317
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
Smith
EUGENE DIETZGEN CO., CHICAGO

PLATE 10.



Curves showing the relation between load and slip of specimens containing ½ inch round rods.
1—2—4 mixture.
30 days old.
Load in lbs. per sq. inch.
Slip in inches.
500
400
300
200
100
0
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
251
254
255
253
Smith
EUGENE DIETZGEN CO., CHICAGO.

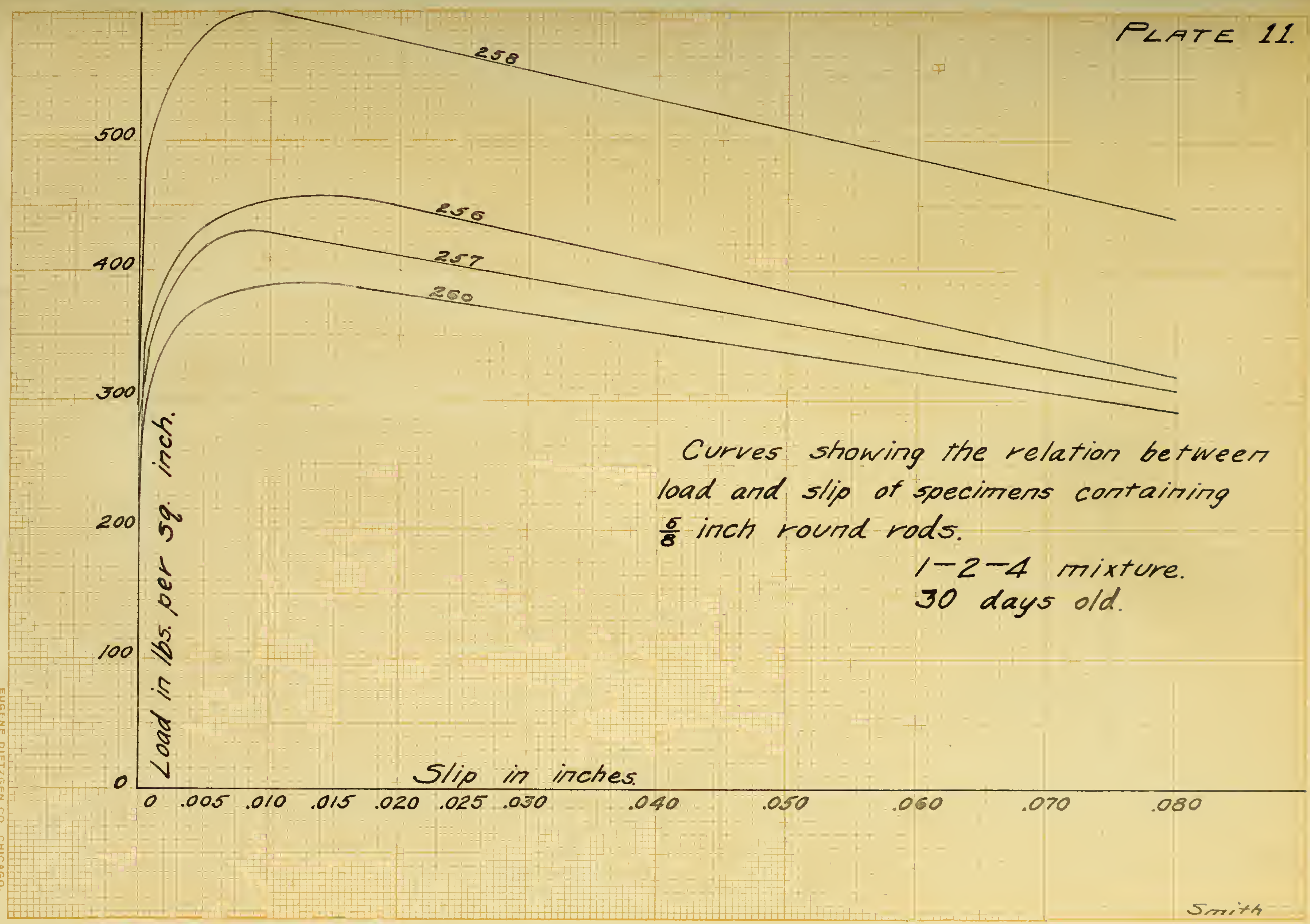
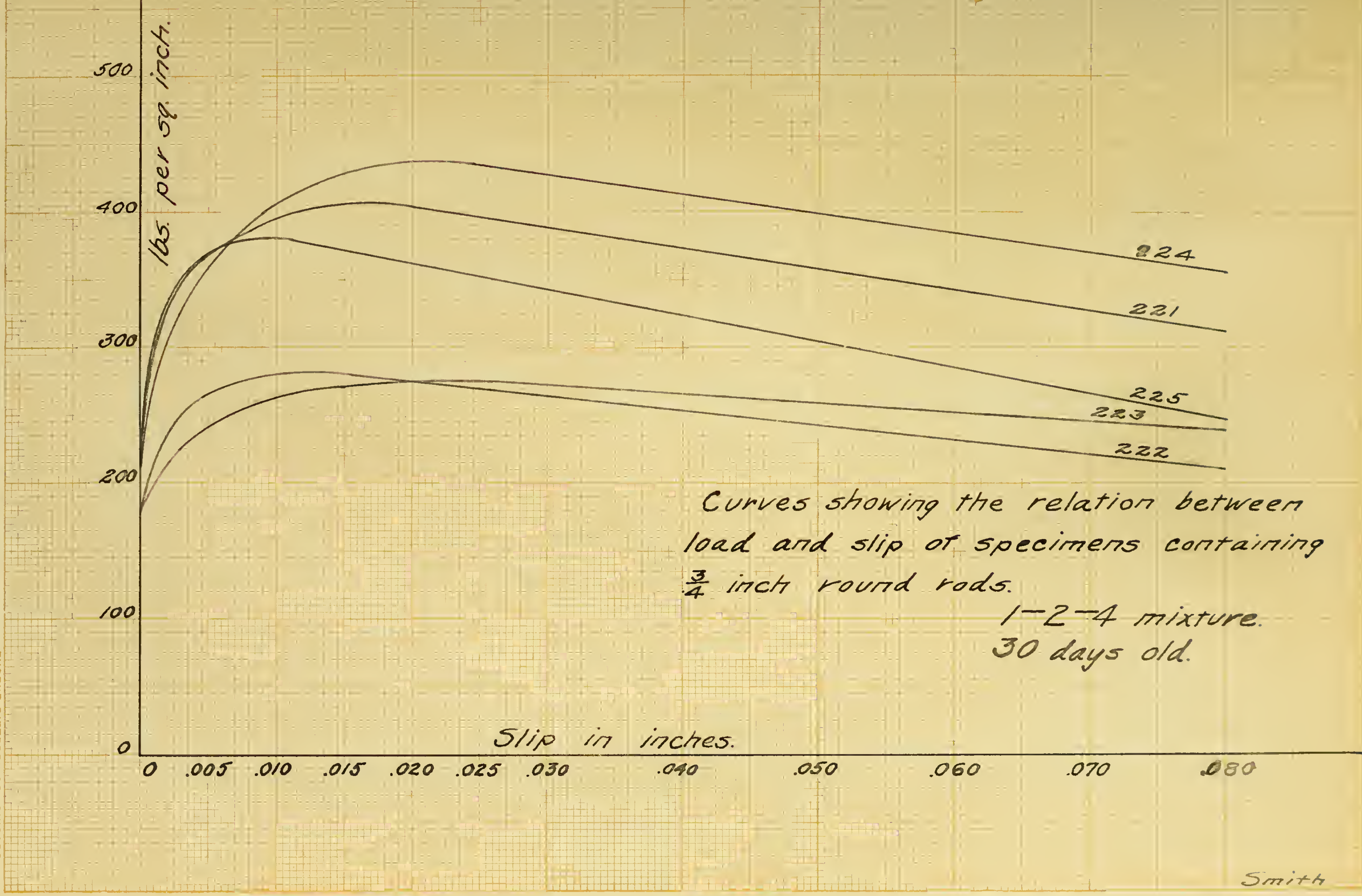


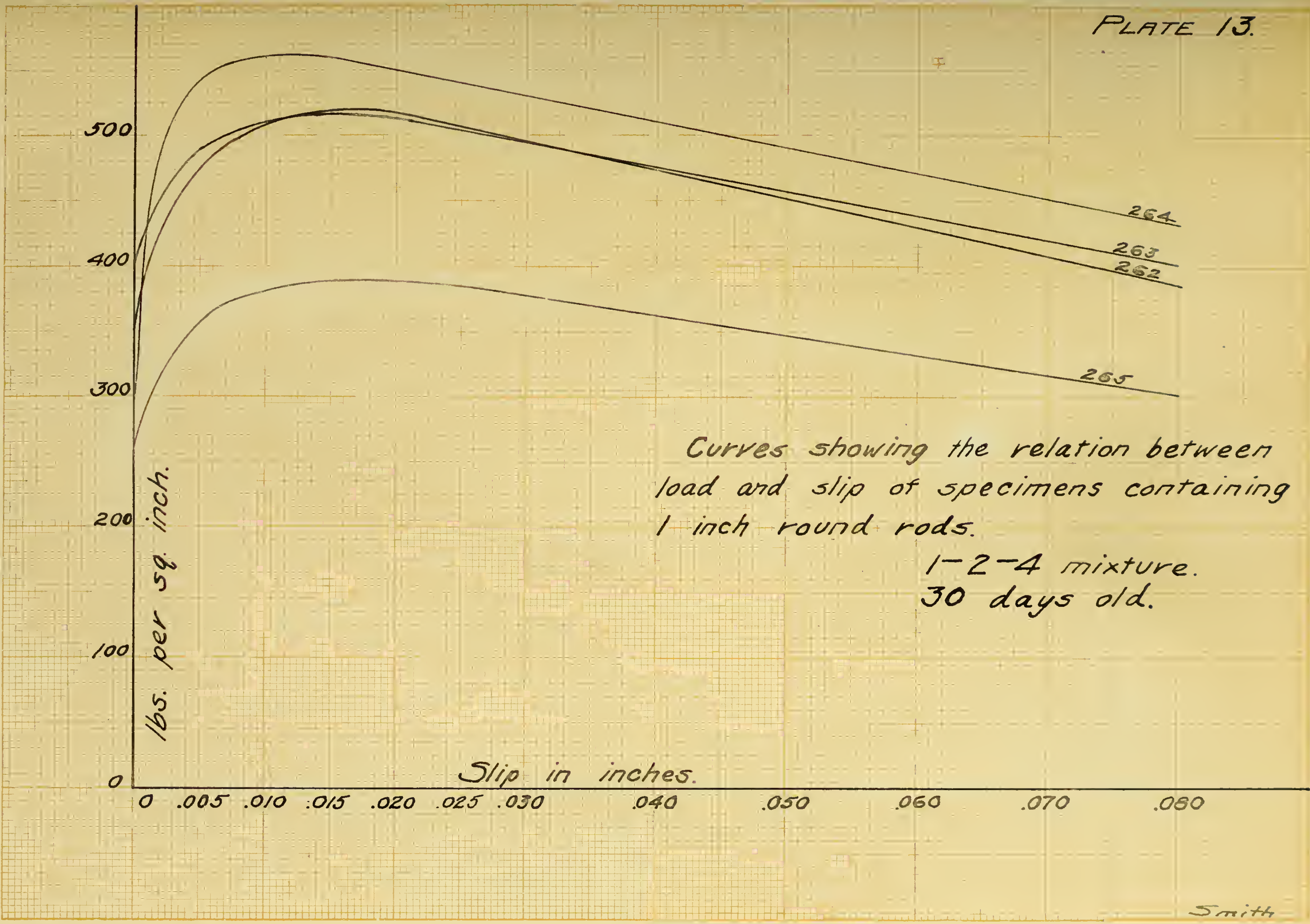
PLATE 11.
258
256
257
260
500
400
300
200
100
0
Load in lbs. per sq. inch.
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
Curves showing the relation between load and slip of specimens containing 5/8 inch round rods.
1-2-4 mixture.
30 days old.
Smith
EUGENE DIETZGEN CO., CHICAGO.

PLATE 12.



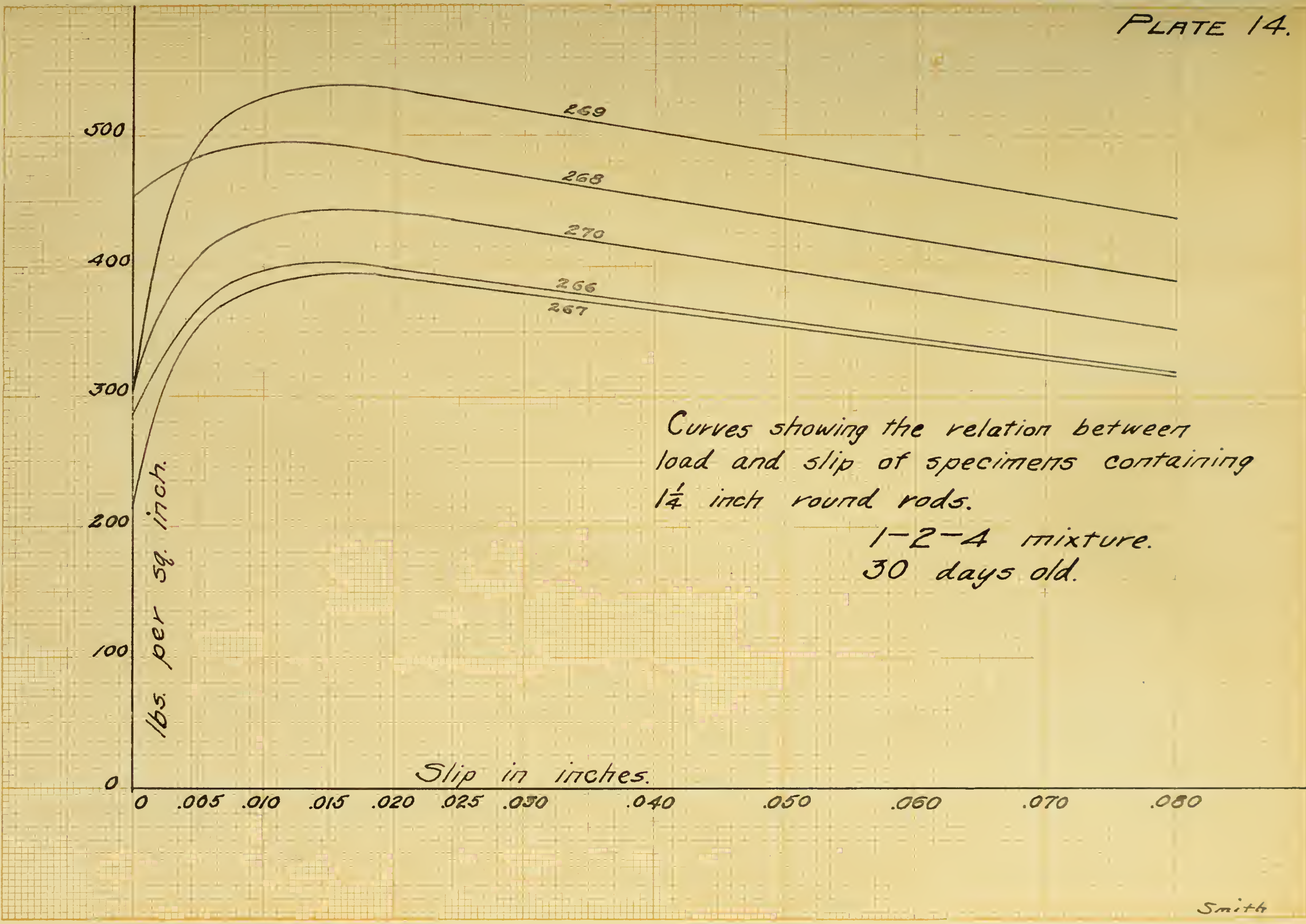
lbs. per sq. inch.
500
400
300
200
100
0
224
221
225
223
222
Curves showing the relation between load and slip of specimens containing $\frac{3}{4}$ inch round rods.
1-2-4 mixture.
30 days old.
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
Smith
EUGENE DIETZGEN CO., CHICAGO.

PLATE 13.



264
263
262
265
500
400
300
200
100
0
lbs. per sq. inch.
Slip in inches.
0 .005 .010 .015 .020 .025 .030 .040 .050 .060 .070 .080
Curves showing the relation between load and slip of specimens containing 1 inch round rods.
1-2-4 mixture.
30 days old.
Smith
EUGENE DIETZGEN CO., CHICAGO

PLATE 14.



500
400
300
200
100
0
lbs. per sq. inch.
269
268
270
266
267
Curves showing the relation between load and slip of specimens containing $1\frac{1}{4}$ inch round rods.
1-2-4 mixture.
30 days old.
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
Smith

PLATE 15.

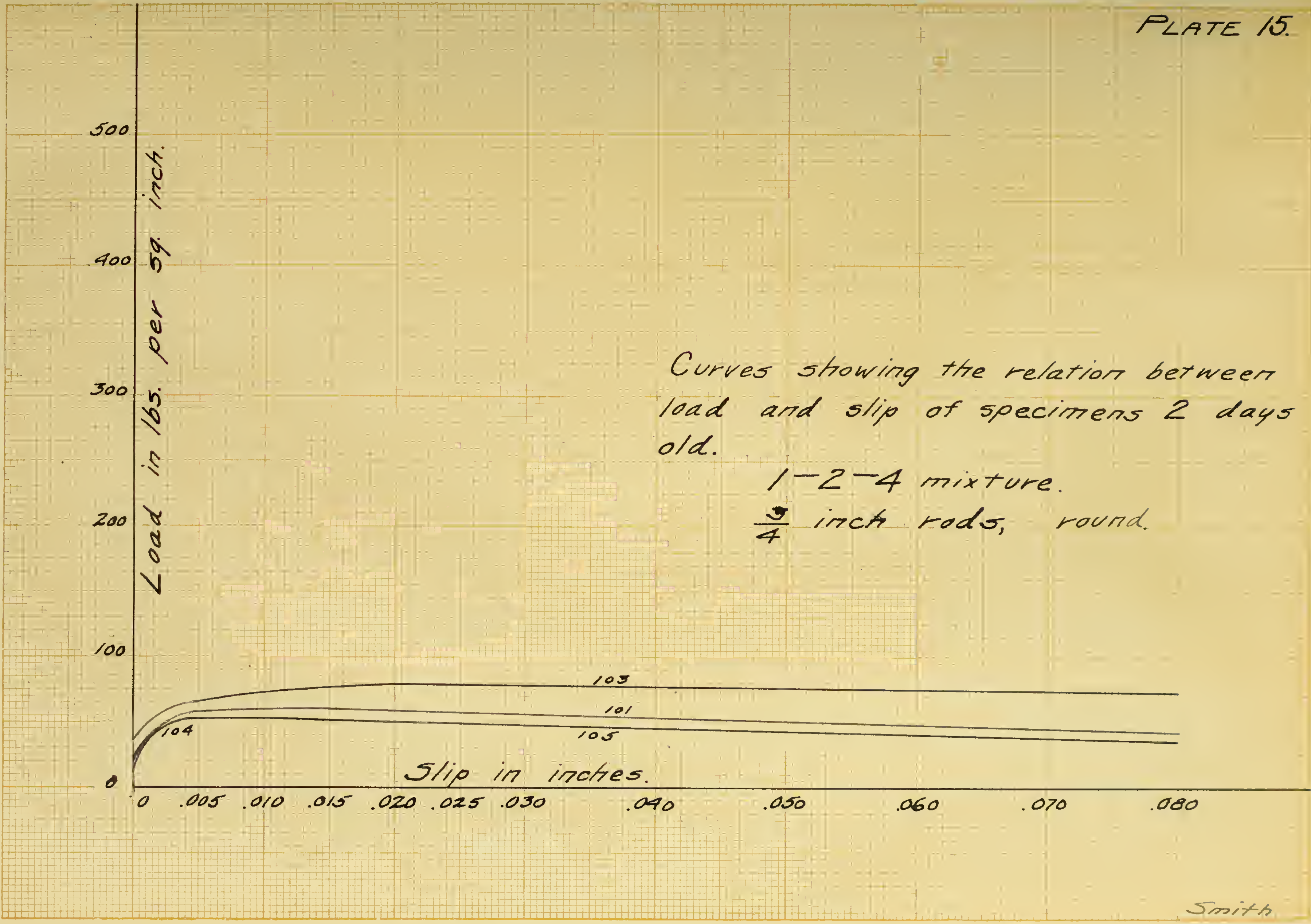

Curves showing the relation between load and slip of specimens 2 days old.
1-2-4 mixture.
3/4 inch rods, round.
Load in lbs. per sq. inch.
500
400
300
200
100
0
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
103
101
104
105
Smith

PLATE 16.

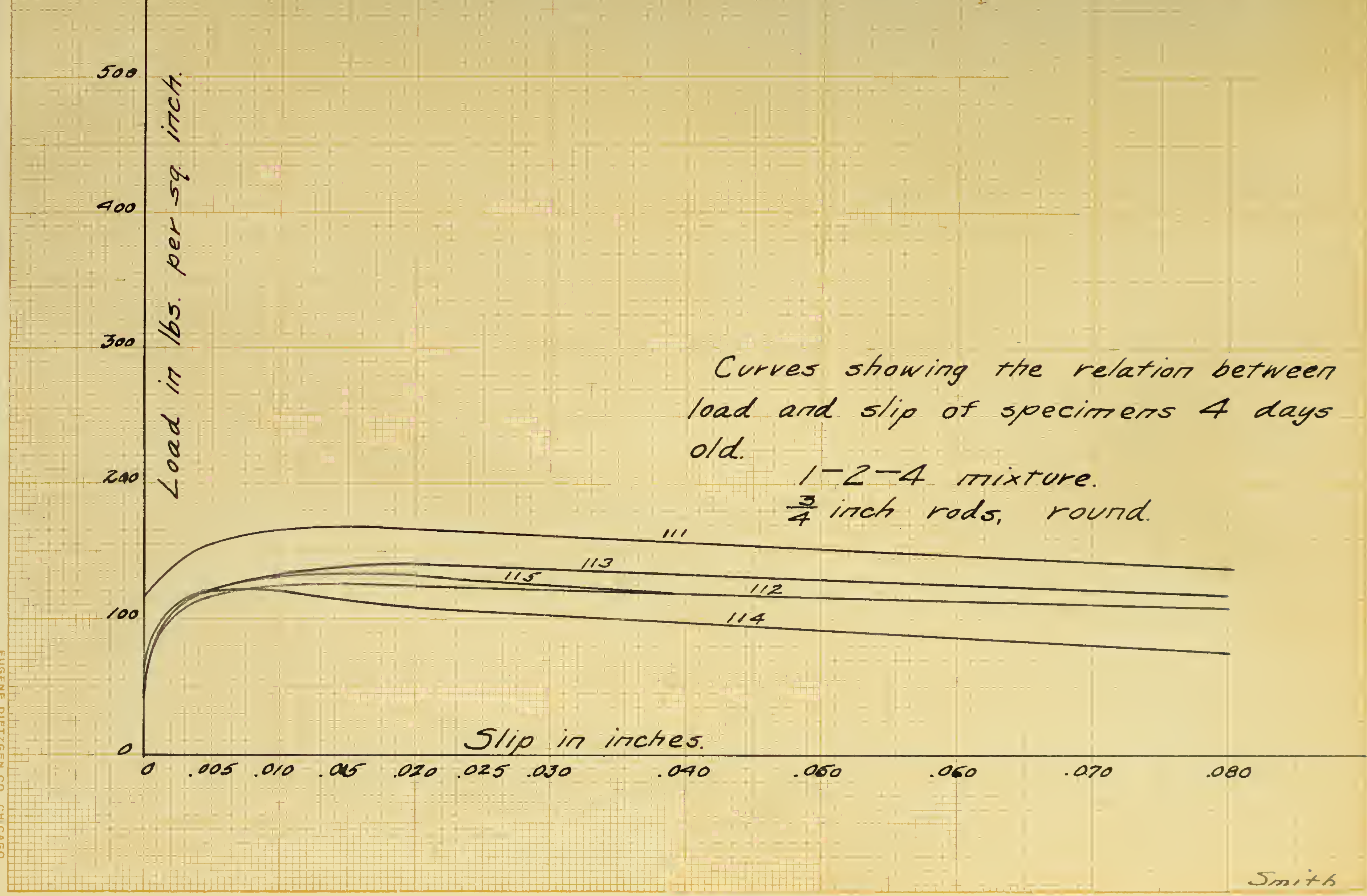

Curves showing the relation between load and slip of specimens 4 days old.
1-2-4 mixture.
$\frac{3}{4}$ inch rods, round.
Load in lbs. per sq. inch.
500
400
300
200
100
0
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
111
113
115
112
114
Smith
EUGENE DIETZGEN CO., CHICAGO

PLATE 17.

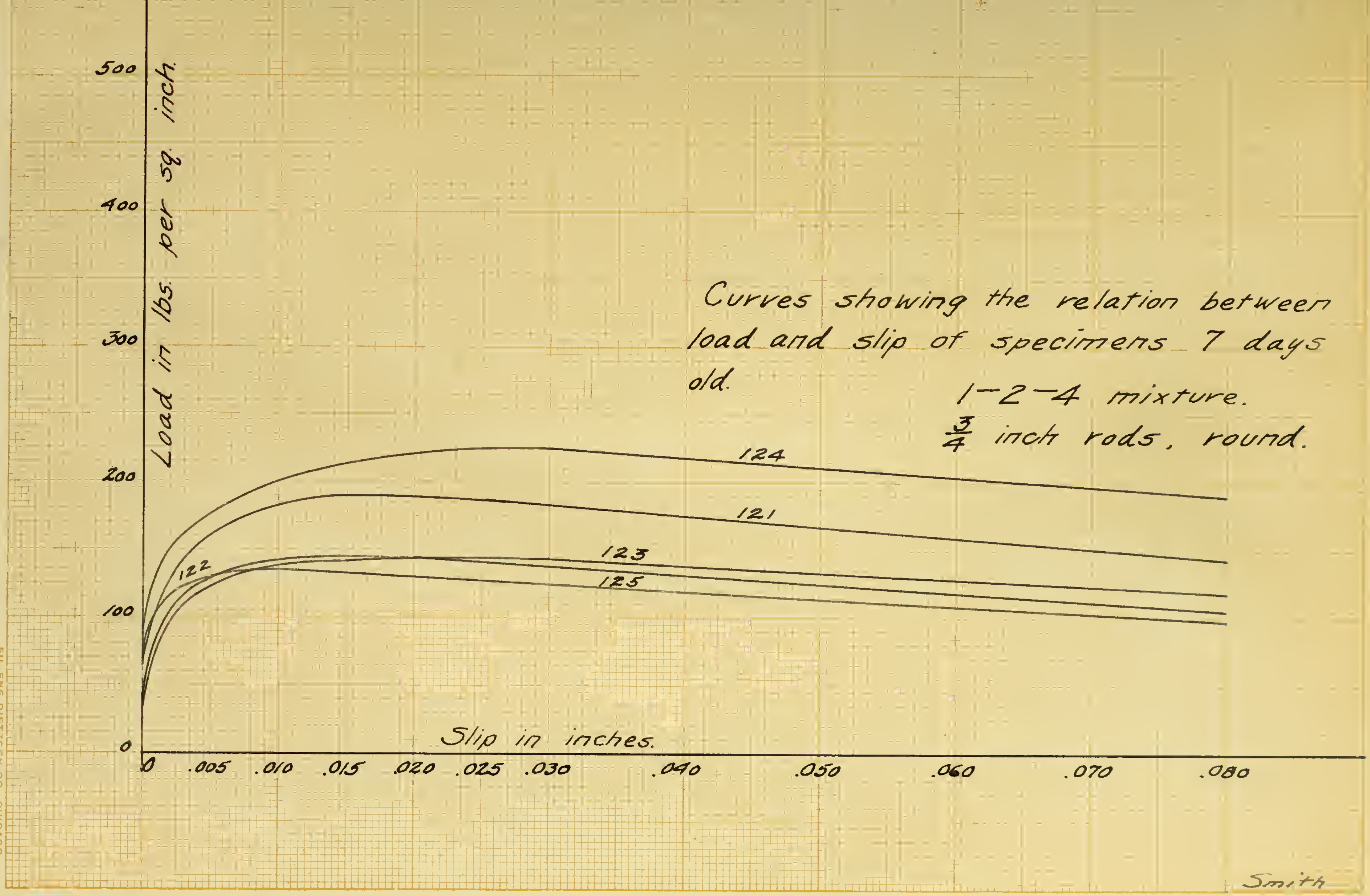
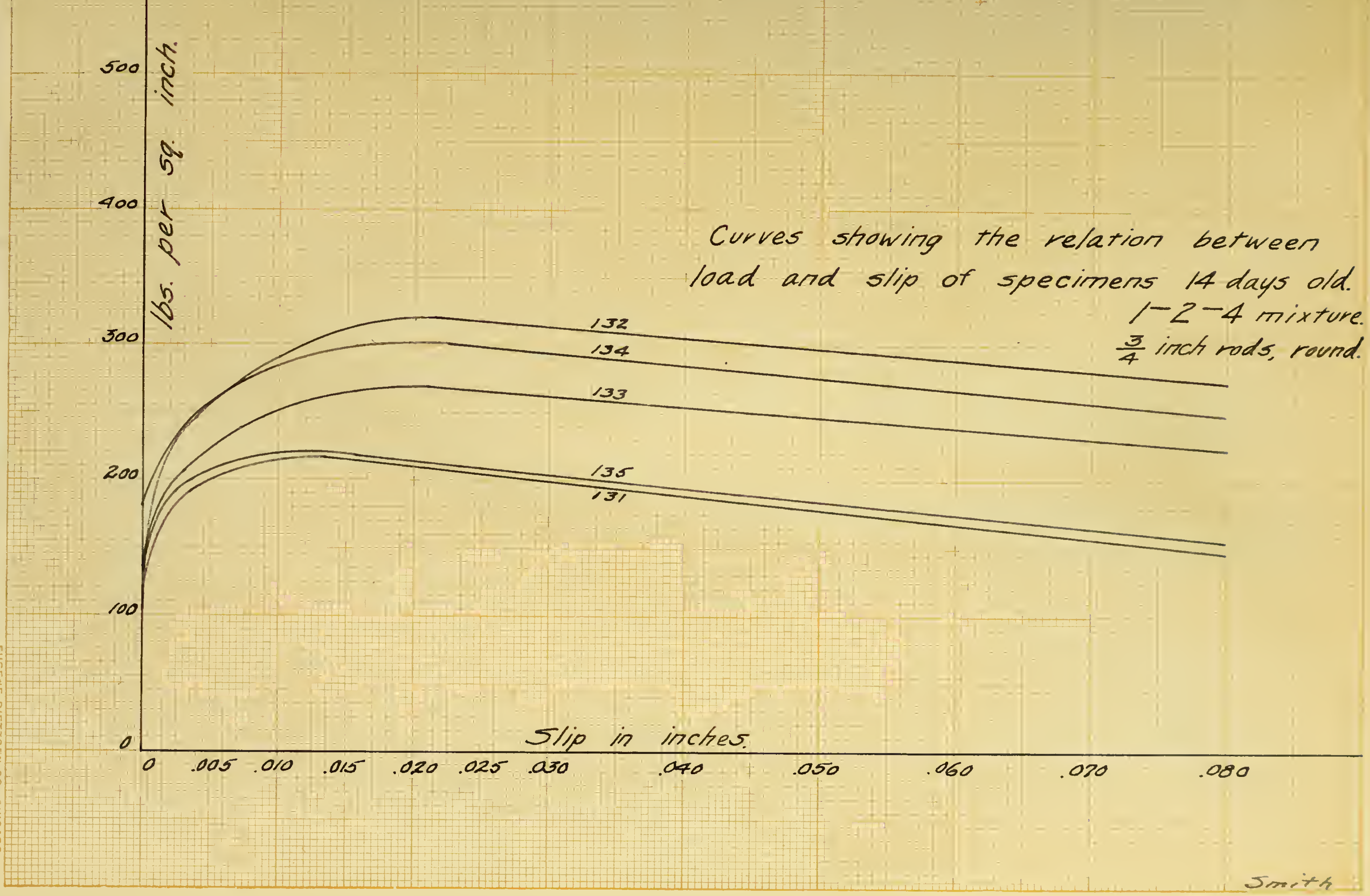
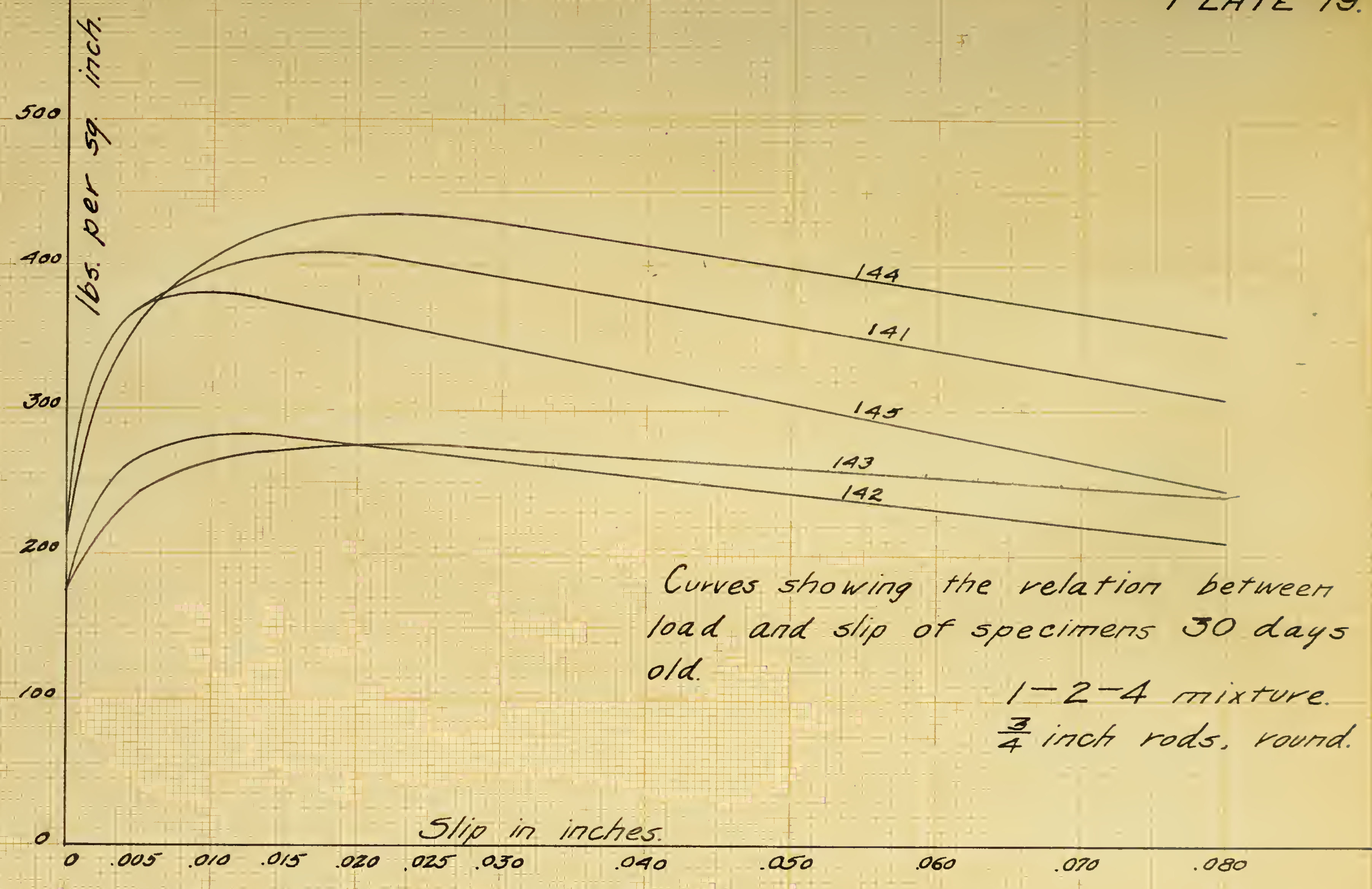

Curves showing the relation between load and slip of specimens 7 days old.
1-2-4 mixture.
$\frac{3}{4}$ inch rods, round.
Load in lbs. per sq. inch.
500
400
300
200
100
0
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
124
121
123
122
125
Smith

PLATE 18.



Curves showing the relation between load and slip of specimens 14 days old.
1-2-4 mixture.
3/4 inch rods, round.
lbs. per sq. inch.
500
400
300
200
100
0
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
132
134
133
135
131
Smith
EUGENE DIETZGEN CO., CHICAGO.

# PLATE 19.




Curves showing the relation between load and slip of specimens 30 days old.

1-2-4 mixture.

$\frac{3}{4}$ inch rods, round.

Smith

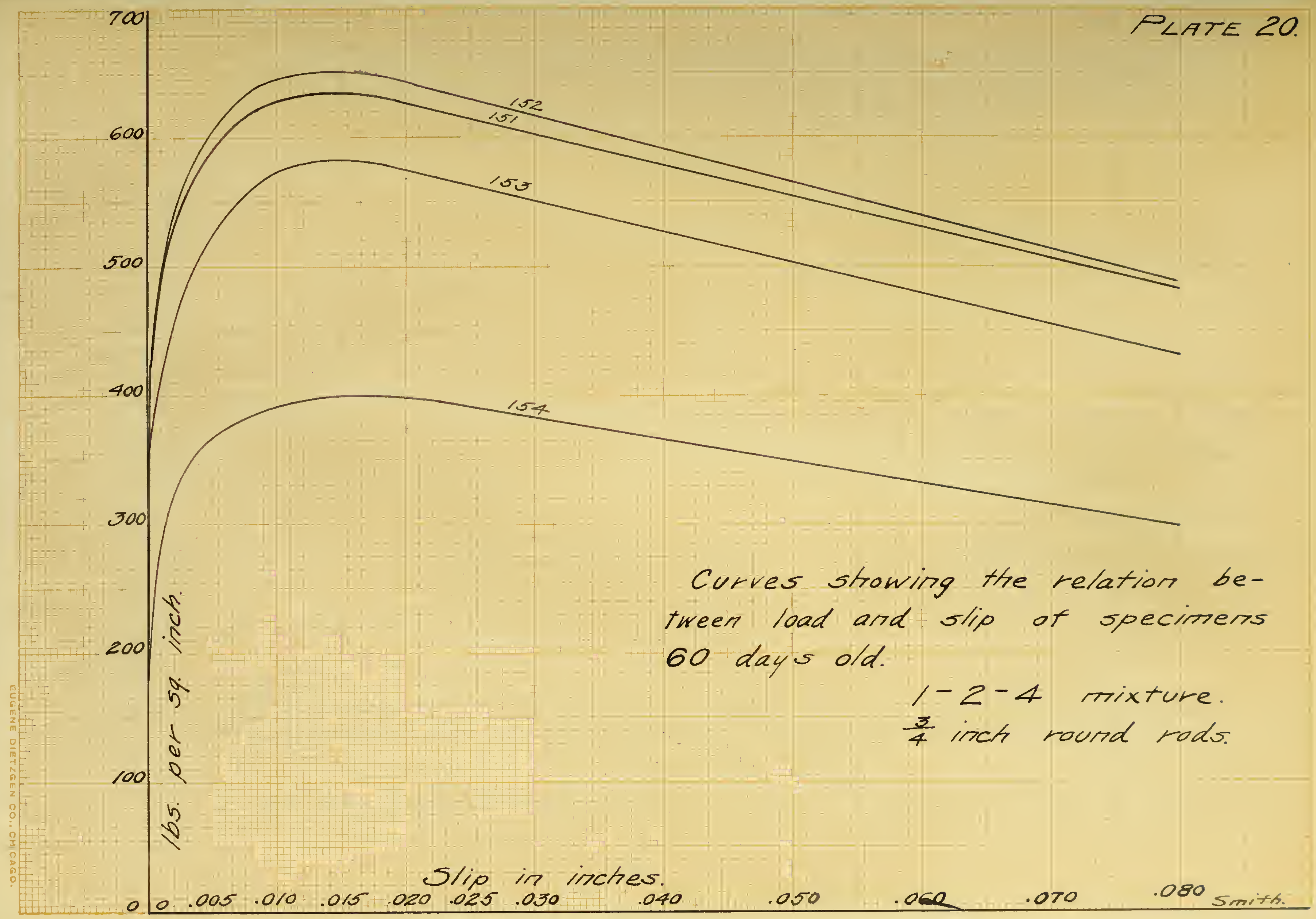
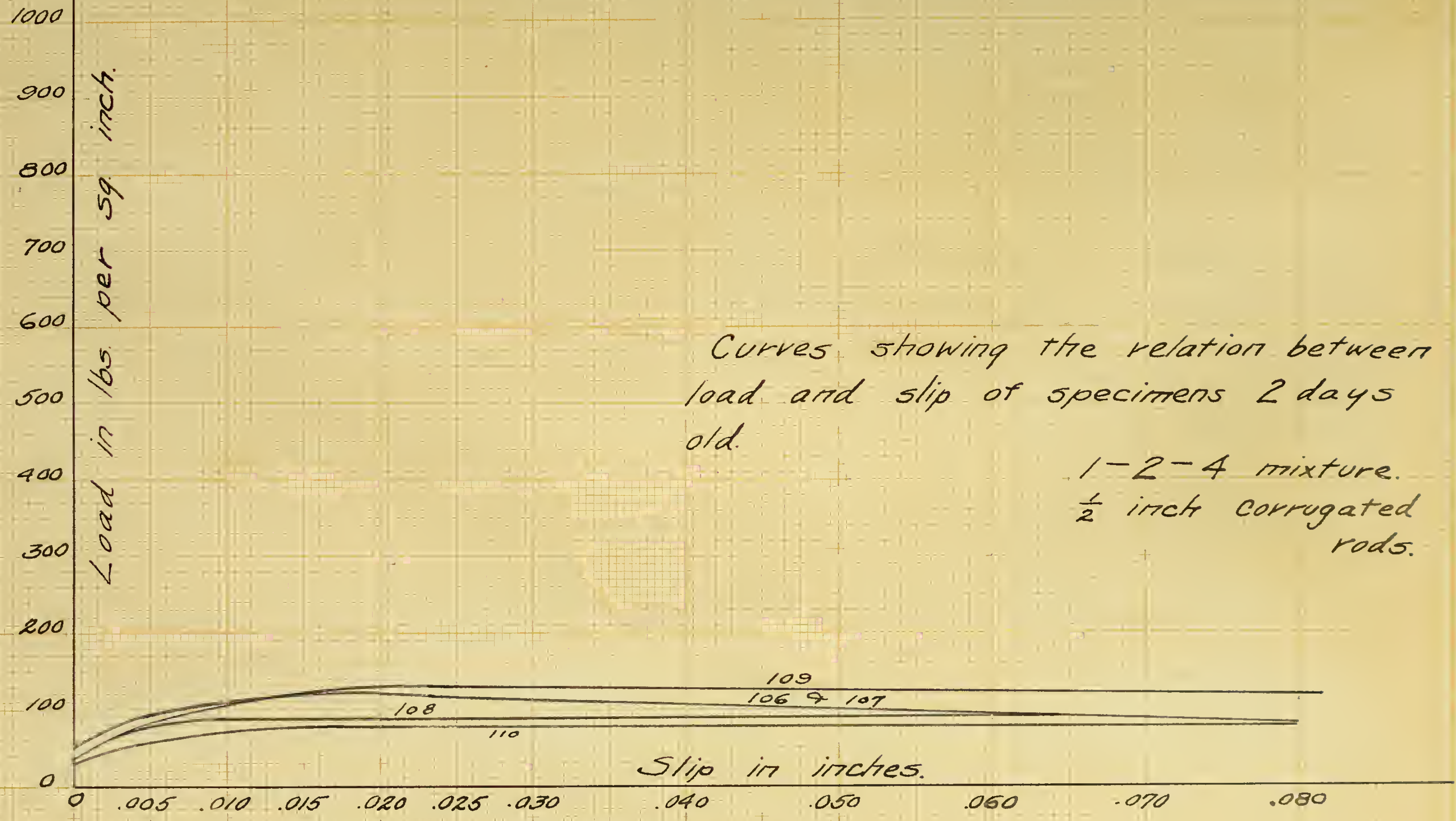


PLATE 20.
Curves showing the relation between load and slip of specimens 60 days old.
1-2-4 mixture.
3/4 inch round rods.
lbs. per sq. inch.
Slip in inches.
152
151
153
154
700
600
500
400
300
200
100
0
0 .005 .010 .015 .020 .025 .030 .040 .050 .060 .070 .080
Smith.
EUGENE DIETZGEN CO., CHICAGO.

PLATE 21.




Smith

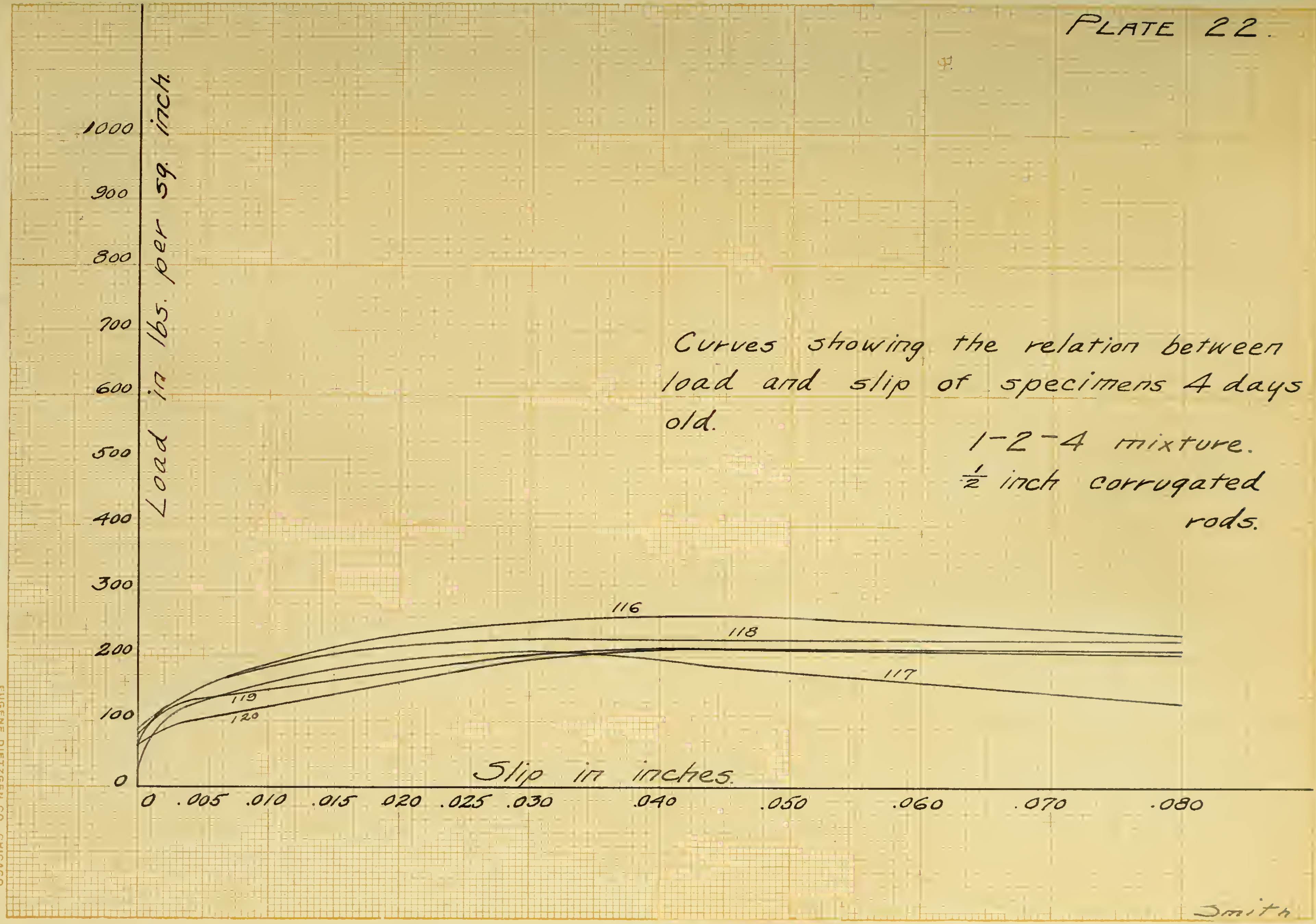


PLATE 22.
Curves showing the relation between load and slip of specimens 4 days old.
1-2-4 mixture.
$\frac{1}{2}$ inch corrugated rods.
Load in lbs. per sq. inch
1000
900
800
700
600
500
400
300
200
100
0
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
116
118
117
119
120
Smith
EUGENE DIETZGEN CO., CHICAGO.

PLATE 23.

Curves showing the relation between load and slip of specimens 7 days old.

1-2-4 mixture.
$\frac{1}{2}$ inch corrugated rods.

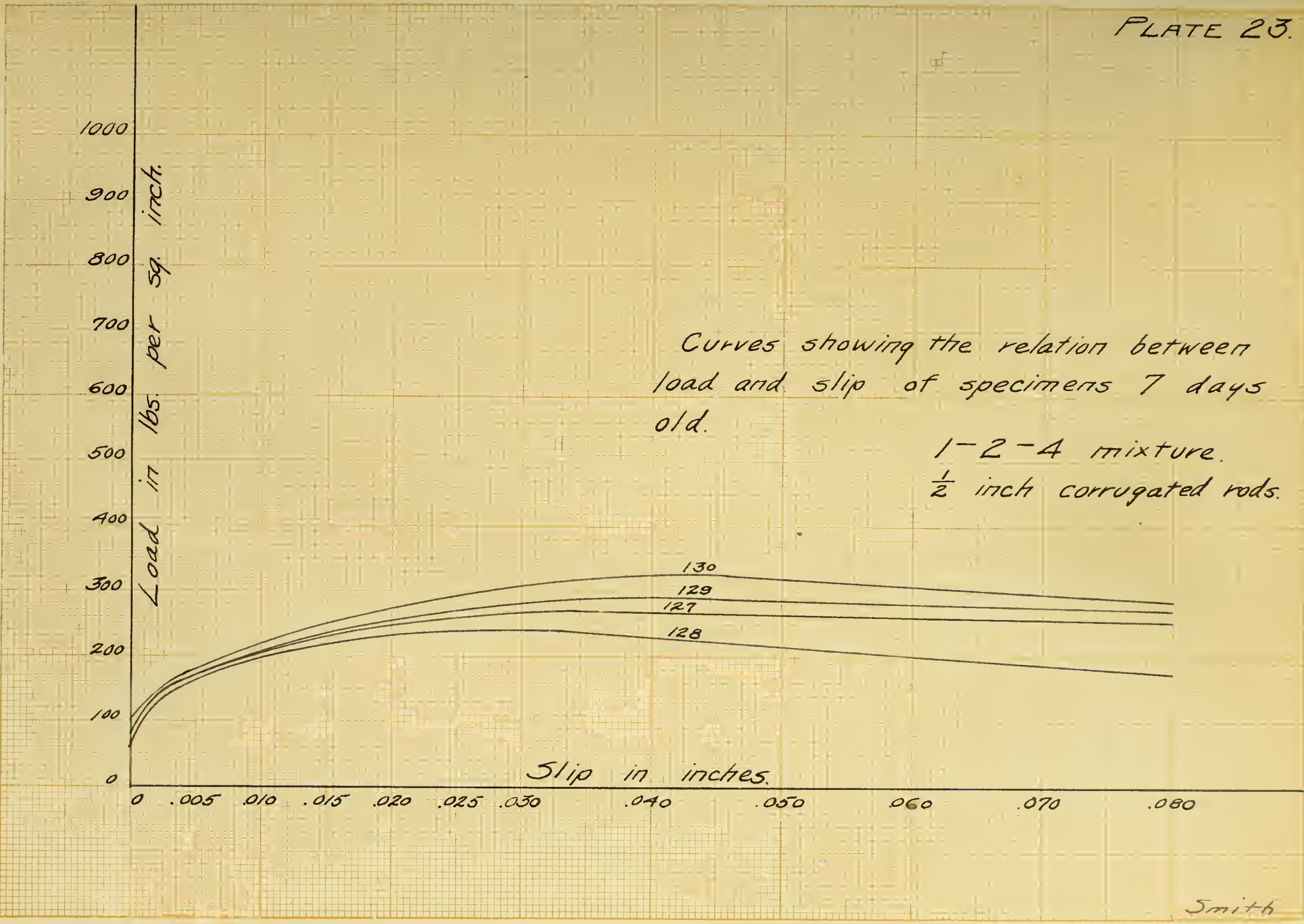
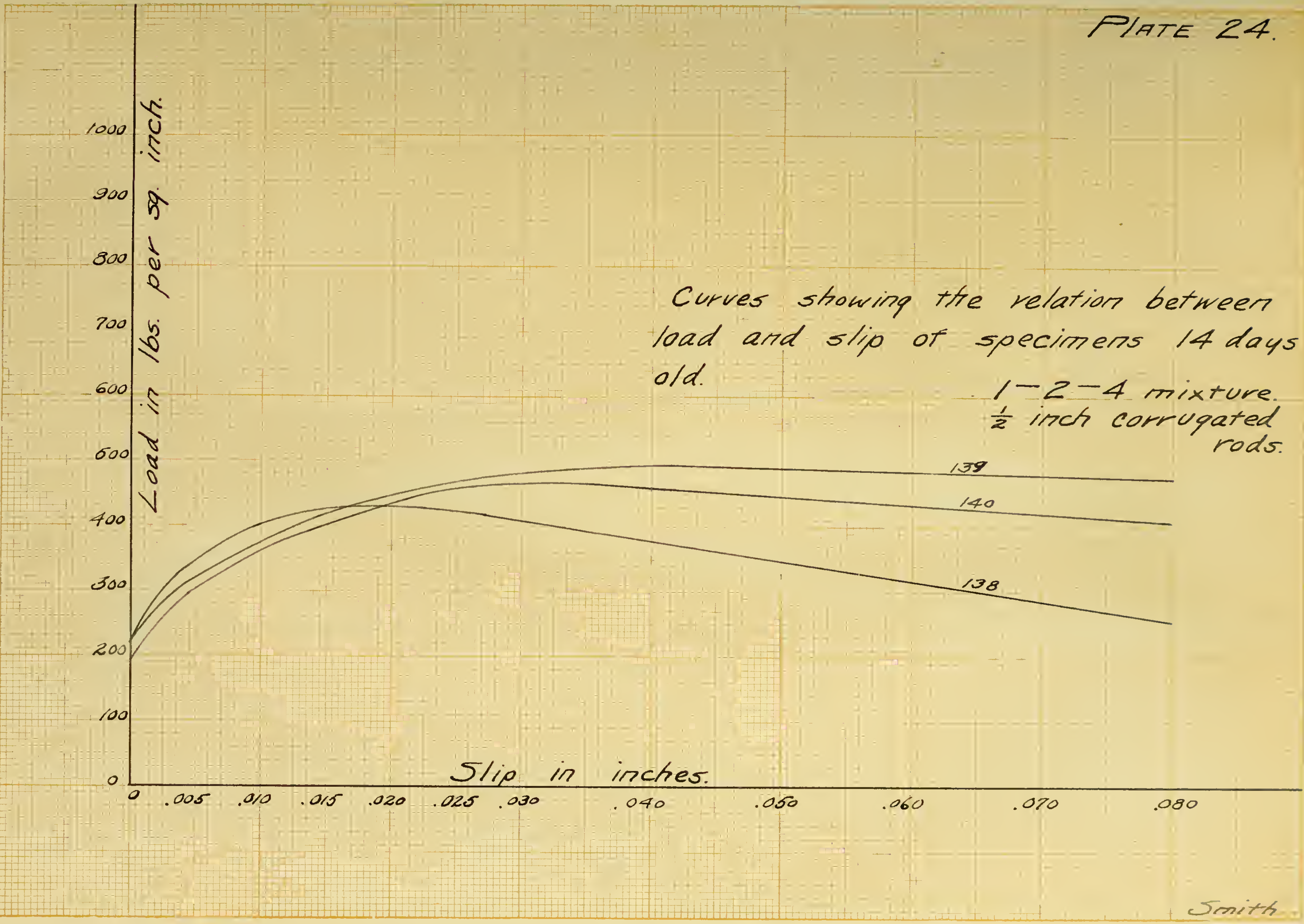


PLATE 24.




Curves showing the relation between load and slip of specimens 14 days old.

1—2—4 mixture.
$\frac{1}{2}$ inch corrugated rods.

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PLATE 25.

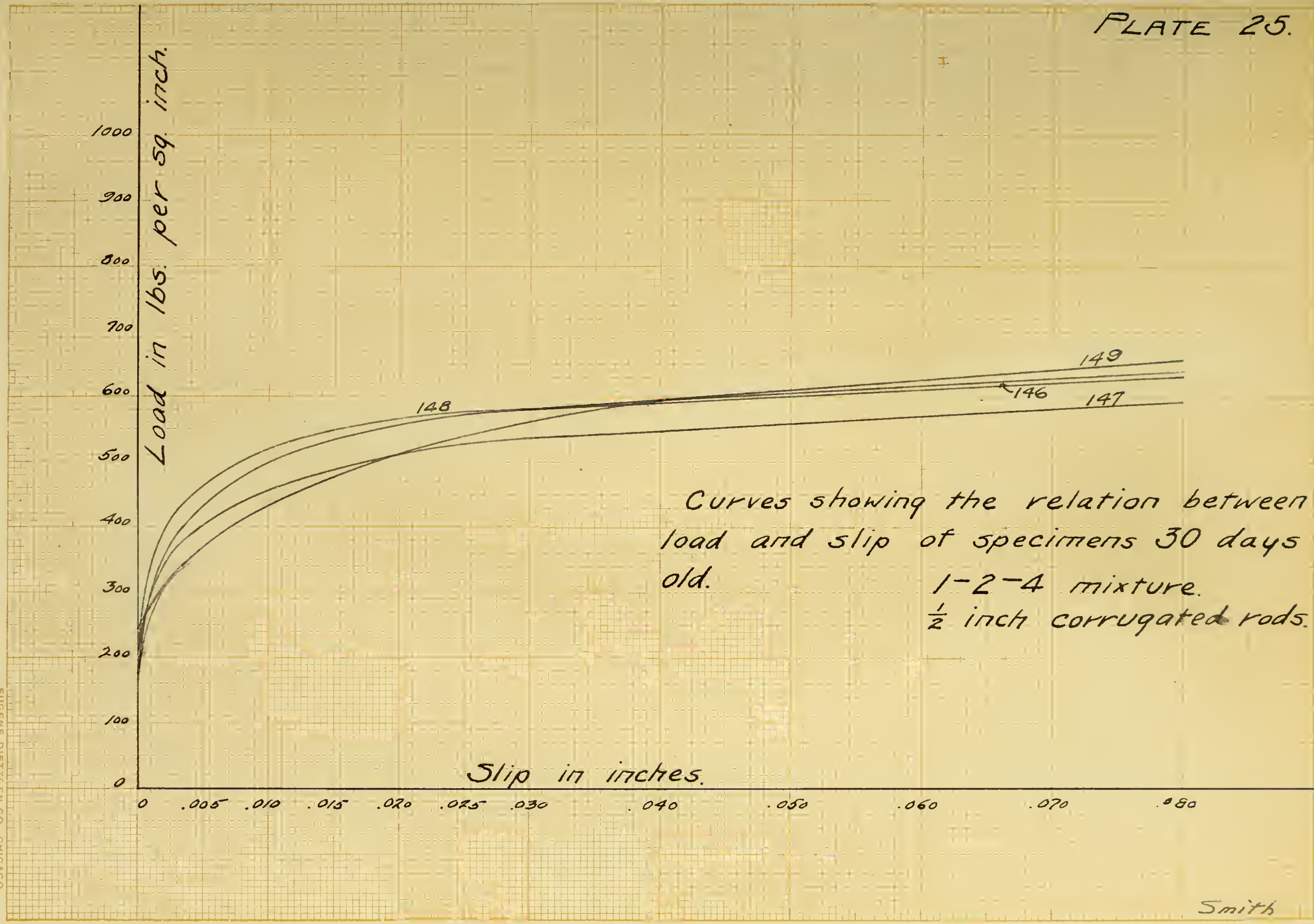
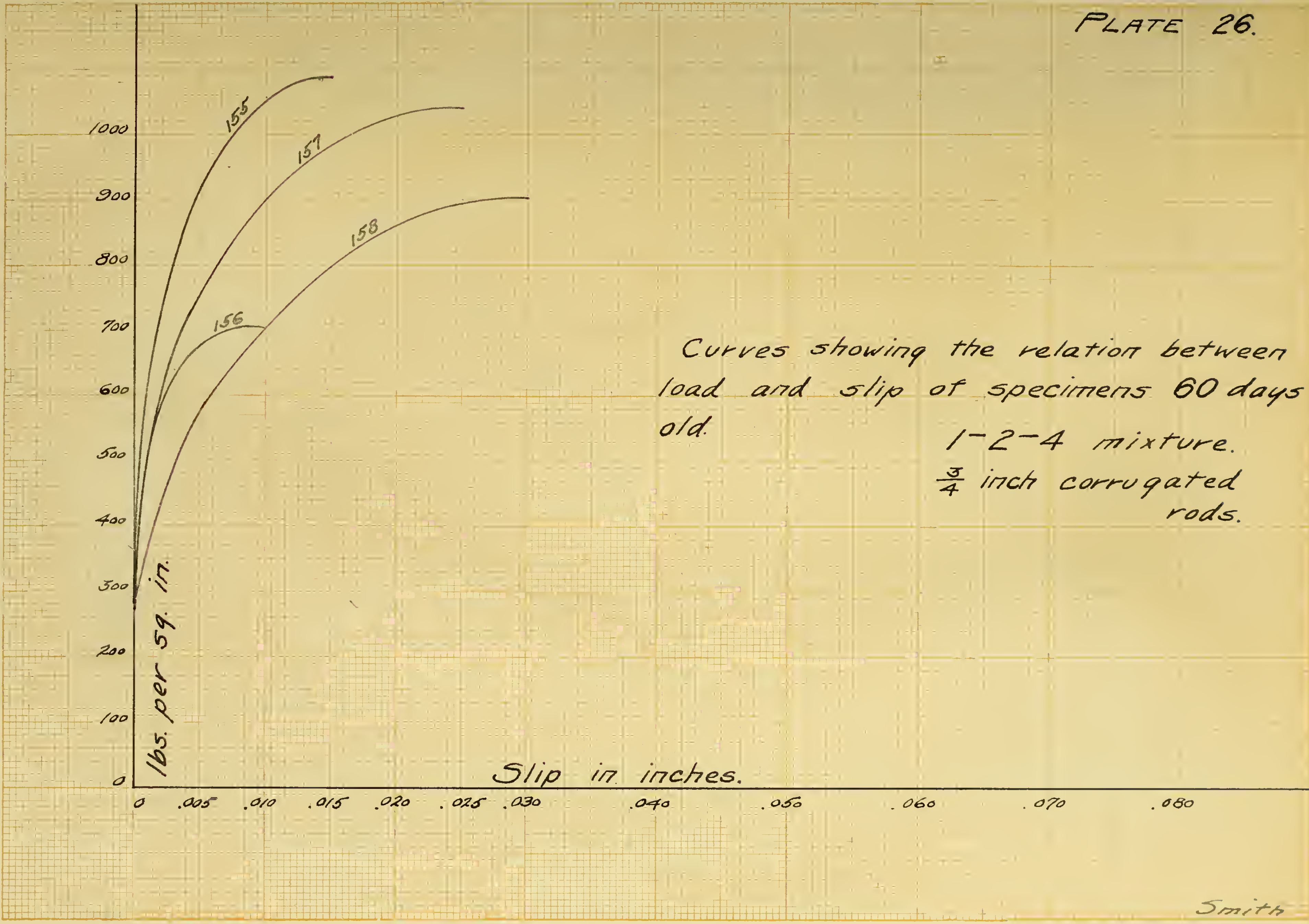

Load in lbs. per sq. inch.
1000
900
800
700
600
500
400
300
200
100
0
149
146
147
148
Curves showing the relation between load and slip of specimens 30 days old.
1-2-4 mixture.
½ inch corrugated rods.
Slip in inches.
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
Smith
EUGENE DIETZGEN CO., CHICAGO.

PLATE 26.



Curves showing the relation between load and slip of specimens 60 days old.
1-2-4 mixture.
3/4 inch corrugated rods.
lbs. per sq. in.
Slip in inches.
0
100
200
300
400
500
600
700
800
900
1000
0
.005
.010
.015
.020
.025
.030
.040
.050
.060
.070
.080
155
157
156
158
Smith

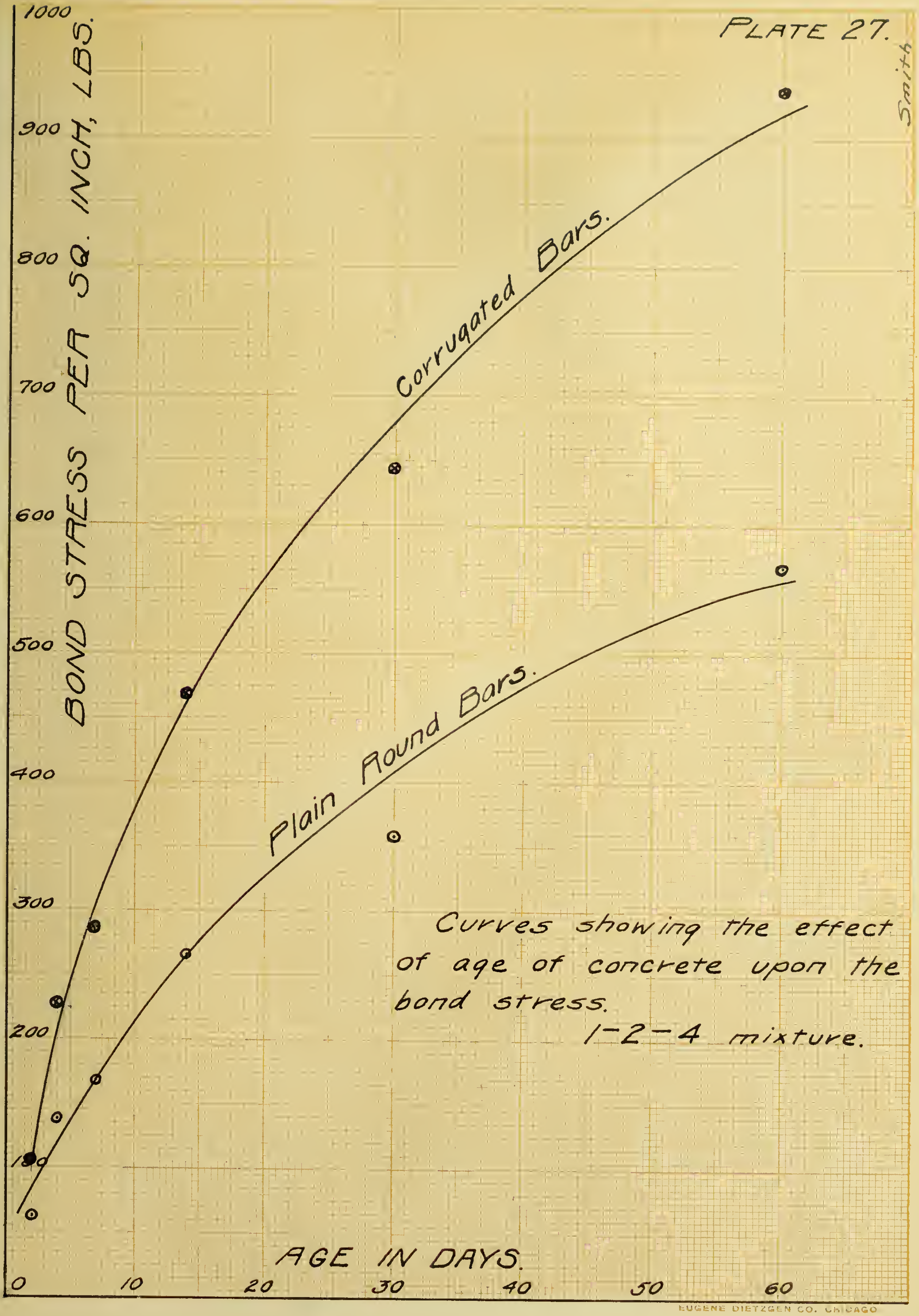
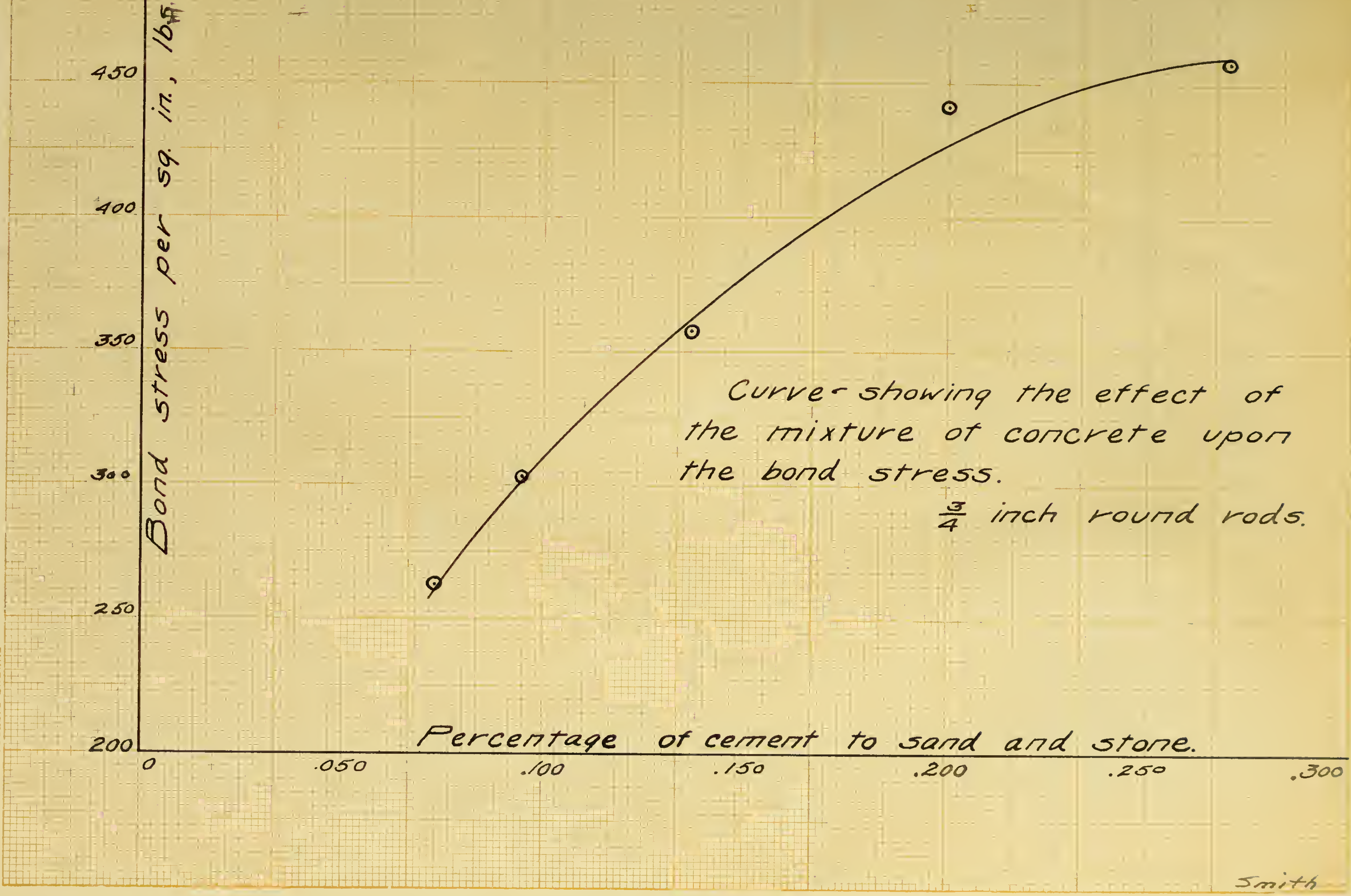


PLATE 27.
Smith
BOND STRESS PER SQ. INCH, LBS.
1000
900
800
700
600
500
400
300
200
100
Corrugated Bars.
Plain Round Bars.
Curves showing the effect of age of concrete upon the bond stress.
1-2-4 mixture.
AGE IN DAYS.
0
10
20
30
40
50
60
EUGENE DIETZGEN CO. CHICAGO

PLATE 28.




EUGENE DIETZGEN CO., CHICAGO.

## V. CONCLUSIONS.

1. Discussion and Interpretation of Results.

Tables I and VI, and Plates 1 to 5 inclusive, show the effect of the mixture of the concrete upon the bond stress. It is seen by the summary that the bond stress increases with the richness of the mixture, the 1-1-2 mixture giving results 74 per cent. greater than the 1-4-8 mixture.

Tables II and VI and Plates 6 to 9 inclusive, show the effect of storage upon bond stress. These results do not show a very large variation for the different methods of storage, and it can therefore be supposed that the conditions of storagedo not effect the bond stress to any large extent, at least for the age of specimens tested. The specimens stored in air give greater values than those store in damp sand, but the difference is not so great that it can be stated that such would always be the case.

Tables III and VI and Plates 10 to 14 inclusive,show the results obtained by the use of various sizes of reinforcing bars. The bond stresses for the different sizes do not vary to any large extent, except that for the 3/4-in. bars, and this is probably due to the fact that these specimens were made from a different batch of concrete from the rest. It seems evident from these results that the unit bond stress is not effected by the size of the bar, but by the condition of its surface.

Tables IV and VI and Plates 15 to 21 inclusive, show

results of age of concrete on bond stress for plain rods, and Tables V and VI and Plates 22 to 28 inclusive, show the same relation for corrugated bars. It is seen that the unit bond stress runs considerable higher all the way through for the corrugated bars than for the round ones. As would be expected, the bond stress increases with the strength of the concrete, being quite small for the 2 and 4 day tests, due to the greenness of the concrete.